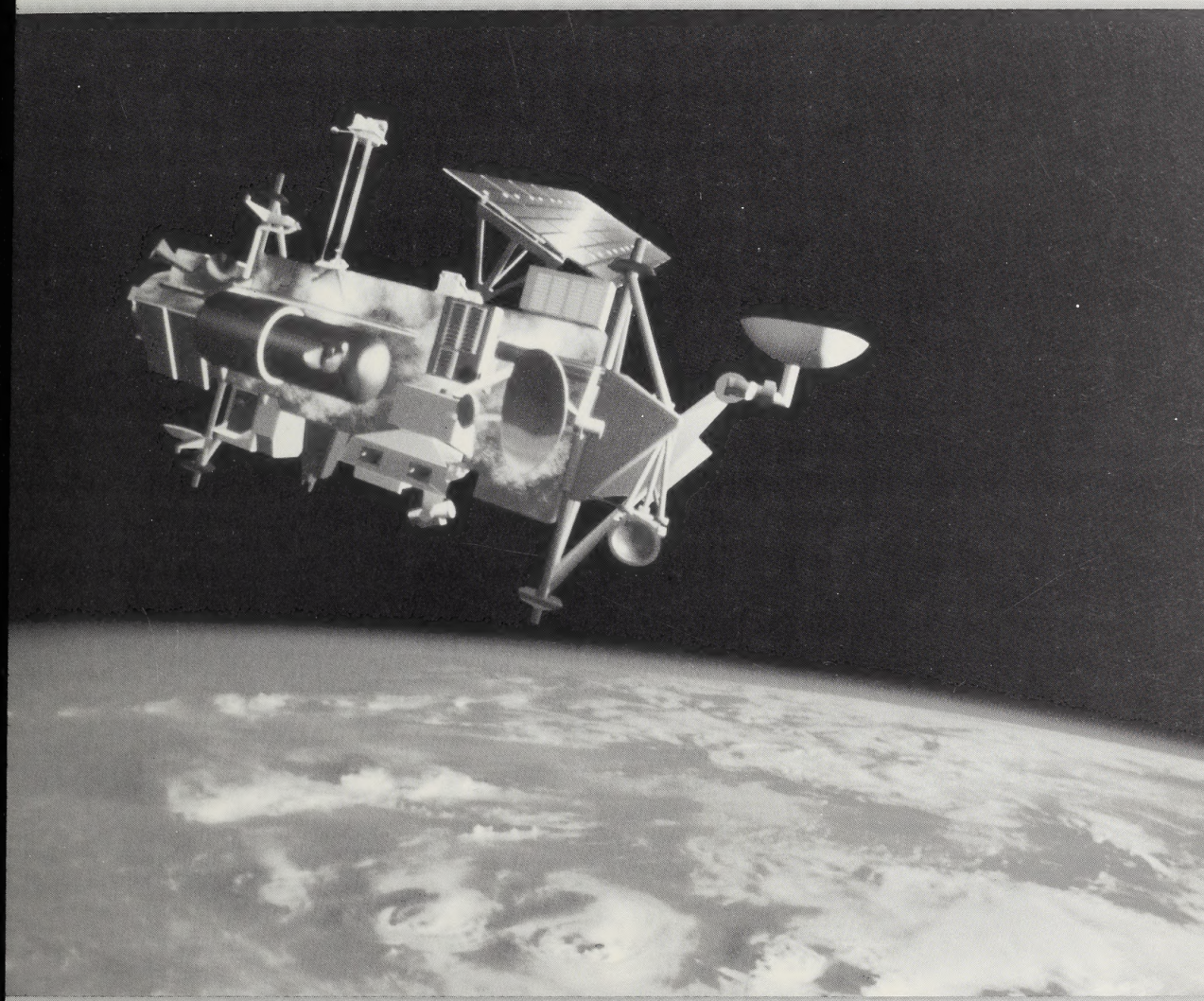
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Science 20



MODULE 7

Motion and Newton's Laws

Distance Learning

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Science 20

Module 7

Motion and Newton's Laws

Alberta EDUCATION

Distance Learning

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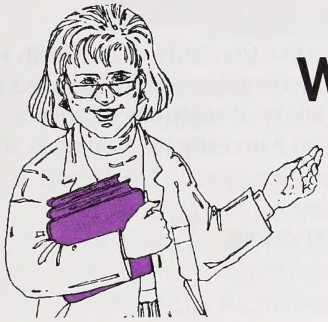
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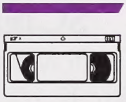
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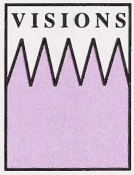
Welcome to Module 7!

We hope you'll enjoy your study of Motion and Newton's Laws.

To make your learning a bit easier, watch the referenced videocassettes whenever you see this icon.



When you see this icon, study the appropriate pages in your textbook.



Good Luck!

COURSE OVERVIEW

This course contains eight modules. Modules 1 and 2 involve the study of the Earth's physical features and past life history. Modules 3 and 4 involve the study of life and its interaction with the Earth. Modules 5 and 6 involve the study of solutions as well as how chemistry is used for everyday things. Modules 7 and 8 investigate motion, both on Earth and in space.

The module you are working on is highlighted in a darker colour.

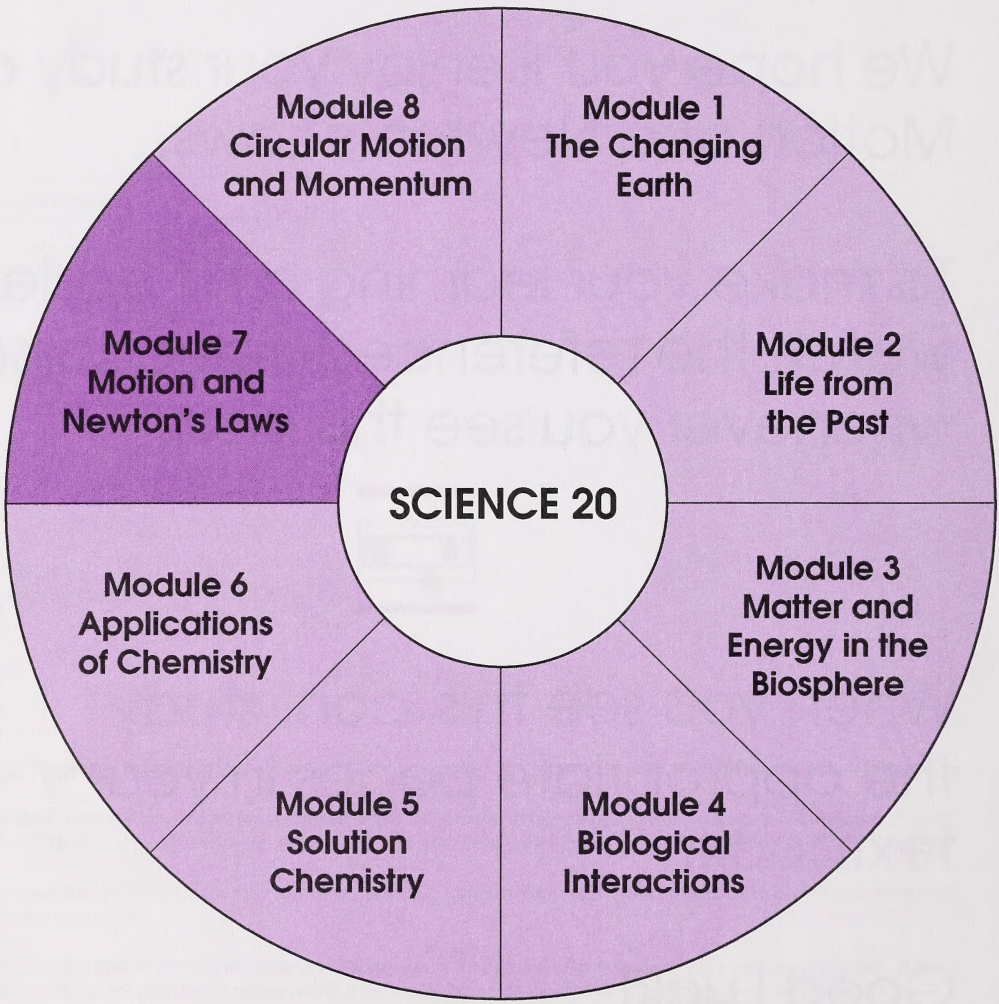


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MODULE OVERVIEW

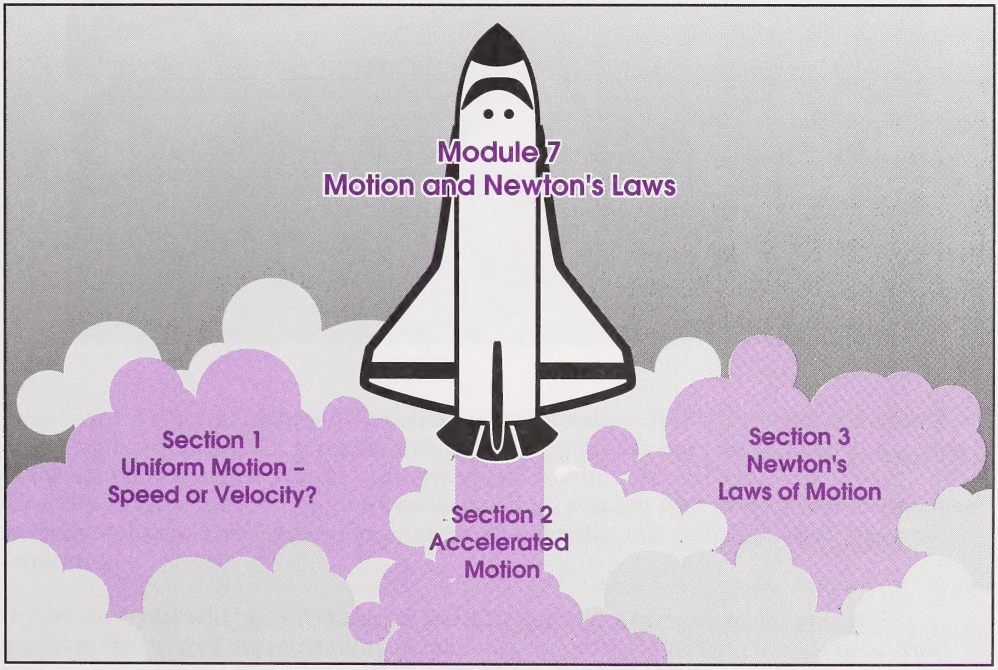
What is the first thought that the expression "the hustle and bustle of a city" brings to your mind? To help you visualize this, imagine yourself standing at a busy intersection. What do you see? A car speeding away from the intersection? A plane flying overhead? A jogger panting by? A bird swooping down to land on a branch?

Can you think of anything that all these activities have in common? Is it motion? Yes, motion is everwhere. Take a closer look at all these activities. Does everything move in the same way? Of course not; so you must ask yourself the following:

- What are the different types of motion? **How** do objects move?
- What causes these different types of motion? **Why** do objects move?

In Science 10, you analysed the simplest type of motion – motion of an object moving at constant speed in a straight line in one direction, or **uniform motion**. To properly analyse this motion, you performed calculations using formulas and graphing methods.

In this module, you will analyse several other types of motion using the same methods. You will also investigate the causes of these motions, which will lead you to the most fundamental laws in physics – Newton's laws of motion.



Evaluation

Your mark in this module will be determined by your work in the Assignment Booklet. You must complete all assignments. In this module you are expected to complete three section assignments. The assignment breakdown is as follows:

Section 1 Assignment	**30 marks**
Section 2 Assignment	**30 marks**
Section 3 Assignment	**40 marks**
TOTAL	**100 marks**

Section

1 Uniform Motion – Speed or Velocity?

It is not surprising that all studies in physics begin with a study of motion, since it is difficult to imagine anything in the universe that does not involve motion. Do you remember your studies of motion in Science 10? You looked at uniform motion and uniform velocity – the two simplest motions. Do you think that was enough to explain the motions of all moving objects in the world around you? As an example, can you imagine all the motions of a person dancing. Look at the motions of the dancers in the photograph.



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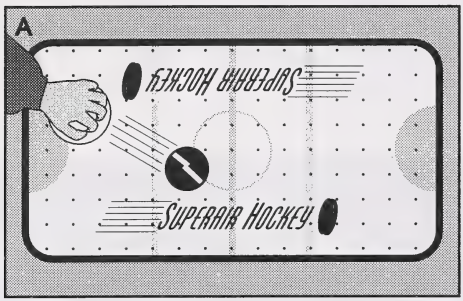
How many motions are there? Are all motions the same? If it is difficult for you to answer these questions, it is because your previous studies only introduced you to two of the simplest types of motion: uniform speed and uniform velocity. But if you carefully analyse the motions of a person dancing, you can spot many differences in the various motions. These differences are used to identify and define all other types of motion.

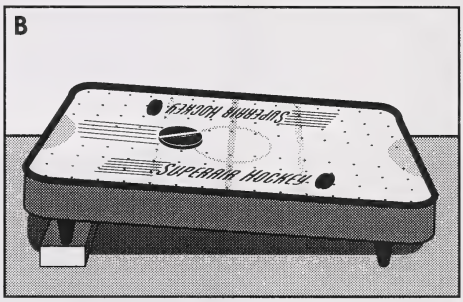
In Section 1 you will be introduced to the different types of motion and you will discover that one of the most fundamental differences in all motion is direction. You will see how developing a sense of direction helps to define the terms necessary to differentiate the simplest motion – unform motion – into two types (uniform speed and uniform velocity). You will then apply this sense of direction to problem solving and extend it to a graphical analysis of motion.

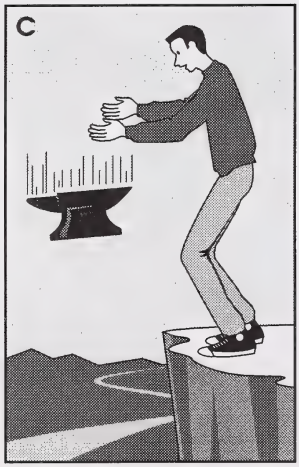
Activity 1: A Sense of Direction!

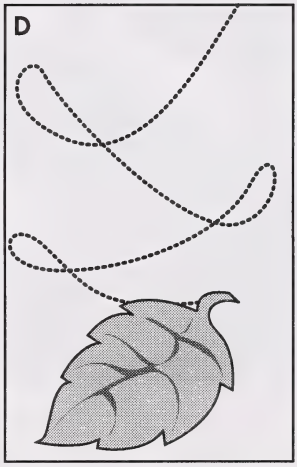
As you are now aware, there are many different types of motion. A basic understanding of the differences in the motions helps to distinguish and identify the different types of motion.

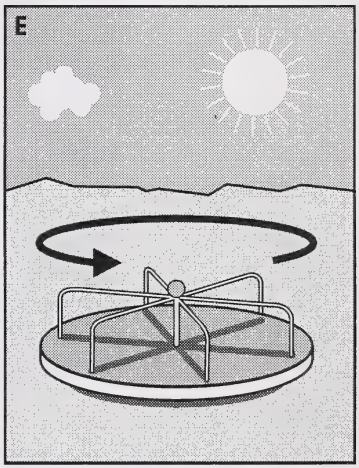
1. The following are diagrams of the major types of motion. Match each diagram to the correct name and description by placing the letter of the diagram in the space provided by the name.

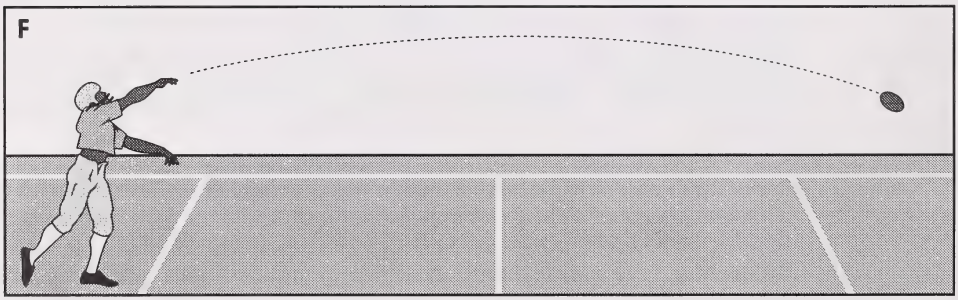


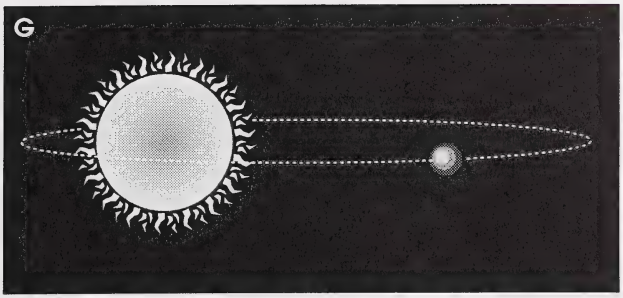


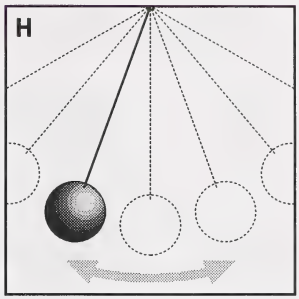












_____ a. **circular accelerated motion** – motion of an object at uniform speed in a curve

_____ b. **accelerated motion due to gravity** or **free fall** – accelerated motion of a falling object in the absence of air resistance

_____ c. **elliptical accelerated motion** – accelerated motion of an object in an oval or ellipse

_____ d. **uniform motion** – motion of an object at uniform speed in a straight line

_____ e. **uniformly accelerated motion** – motion of an object that is changing at a regular rate

_____ f. **non-uniform motion** – motion of an object that is not changing at a regular rate

_____ g. **simple harmonic motion** – a back and forth motion over the same path during equal time intervals

_____ h. **projectile motion** – motion of an object that has a vertical and a horizontal velocity

Check your answers by turning to the Appendix, Section 1: Activity 1.

Now that you are familiar with the different types of motion, you can investigate one of the factors that makes one motion different from another.

Previous studies in motion gave the basics to do some important calculations using formulas involving uniform motion in a straight line. To review how to use the formulas for uniform motion, do the following questions.

2. Suppose you are driving a car at a constant 100 km/h along an unfamiliar, straight stretch of road and you approach an important intersection (as shown in Figure 7.1.).

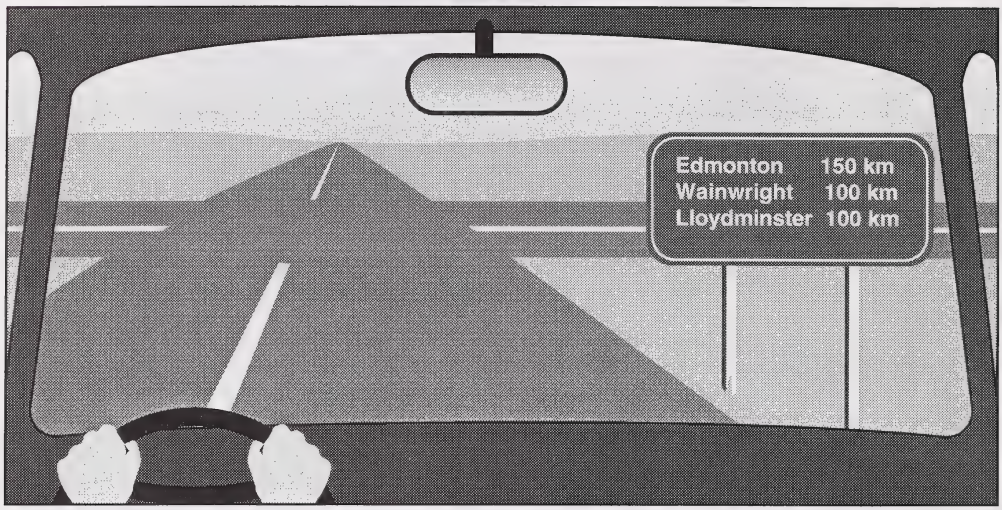


FIGURE 7.1 On a Highway to Edmonton

a. What is the formula involving average speed, distance, and time?

b. State what each variable in the formula from question 2. a. represents.

c. If you are using the equation from question 2. a. to solve the problem, what are the given variables? What is the unknown variable?

d. Rearrange the formula to solve for the unknown.

e. Calculate the time required to drive to Edmonton.

Check your answers by turning to the Appendix, Section 1: Activity 1.

Now that you know how far it is to Edmonton and how long it should take to get there, what additional information do you need? Study the road sign in Figure 7.2.

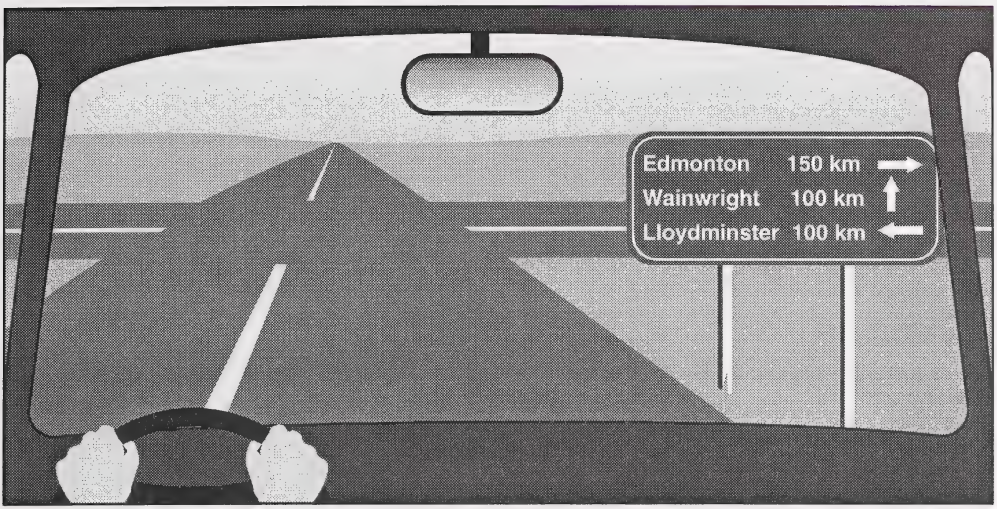


FIGURE 7.2 Edmonton Bound!

3. What additional information do you need to reach Edmonton?

Check your answers by turning to the Appendix, Section 1: Activity 1.

From the answer to question 3 you can see that direction is an important factor in describing motion, since it tells you where to go. But how do you really describe the location of an object or a place? For example, how would you describe the location of Edmonton in Figure 7.2? First, you must choose a **reference point**.

reference point – the starting point or origin to which the location of an object or place is compared

4. In describing the location of Edmonton from Figure 7.2, what is your reference point?

Check your answers by turning to the Appendix, Section 1: Activity 1.

Next, in describing the location of Edmonton, you must state how far it is relative to your reference point. This can be done in two ways:

- If you state that Edmonton is 150 km relative to the intersection, you are only stating how far it is or how much. This is called the **magnitude** of a quantity.

magnitude – indicates only how far or how much

- If you state that Edmonton is 150 km to the right relative to the intersection, you are stating how far it is (magnitude) as well as giving the direction of a quantity.

This sets up a fundamental difference between all measured quantities in physics. Two basic ways to measure quantities in physics are in terms of **scalar quantities** and **vector quantities**.

scalar quantities – quantities that only indicate magnitude

vector quantities – quantities that indicate magnitude and direction

Vector quantities are distinguished from scalar quantities by using the vector notation (→) above the symbol. The (→) indicates that a direction after the magnitude of your quantity is needed.

An example of a scalar quantity would be indicating that the location of Edmonton is 150 km from the intersection. This is called the **distance** to Edmonton, given as $d = 150\ \text{km}$.

distance – a scalar quantity describing how far it is to an object or place

An example of a vector quantity would be indicating that the location of Edmonton is 150 km to the right of the intersection. This would be called the **position** of Edmonton, given as $\vec{d} = 150\ \text{km}$, right.

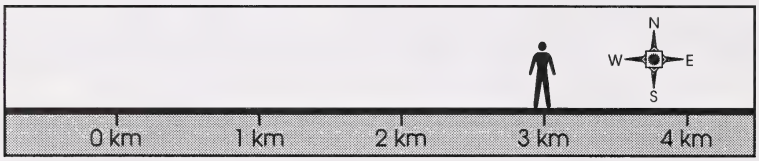
position – a vector quantity describing how far it is to an object or place in a straight line and the direction

5. What are two differences between scalar quantities and vector quantities?

Check your answers by turning to the Appendix, Section 1: Activity 1.

Thus, to properly locate an object or a place, you must state a reference point and state either the distance to or the position of the object or place.

6. Study the following diagram; then answer the questions.



a. What is the distance and the position of the person relative to the 0 km mark?

b. What is the distance and the position of the person relative to the 4 km mark?

Check your answers by turning to the Appendix, Section 1: Activity 1.

Now, if an object travels from one point to another, it is changing its position. To indicate a change in something, use the delta notation (Δ). The following are examples of the use of the delta notation with both scalar and vector quantities.

- scalar quantity – If a car travels 150 km to Edmonton, a change in distance has occurred (given as Δd).

  $\Delta d = 150$ km

- vector quantity – If a car travels 150 km to the right from the intersection to Edmonton, a change in position or a **displacement** has occurred (given as $\Delta \vec{d}$).

  $\Delta \vec{d} = 150$ km, right

displacement – a vector quantity describing a change in position

7. a. What are the two scalar quantities discussed previously?

   b. What are the two vector quantities discussed previously?

VISIONS

8. Read page 370 of your textbook; then answer the following questions.

   a. Give two other examples of scalar quantities.

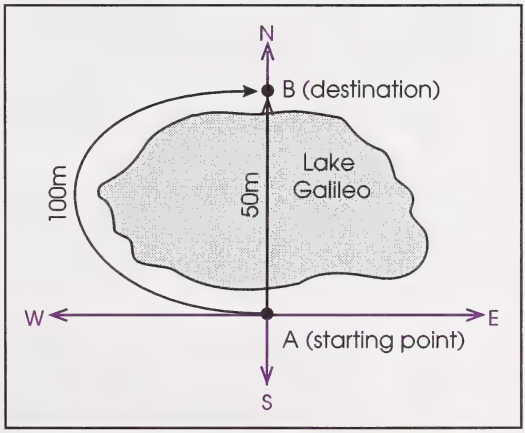
   b. Give another example of a vector quantity.

The following problem illustrates the difference between a scalar displacement and a vector displacement.

9. Two people want to reach Point B from their starting position at A. Myrna walks around Lake Galileo, and Jaydn crosses the lake in a canoe.

   a. What are the distances travelled (Δd) by Myrna and Jaydn?

   b. What are the displacements ($\Delta \vec{d}$) or the changes in position from A to B for Myrna and Jaydn?



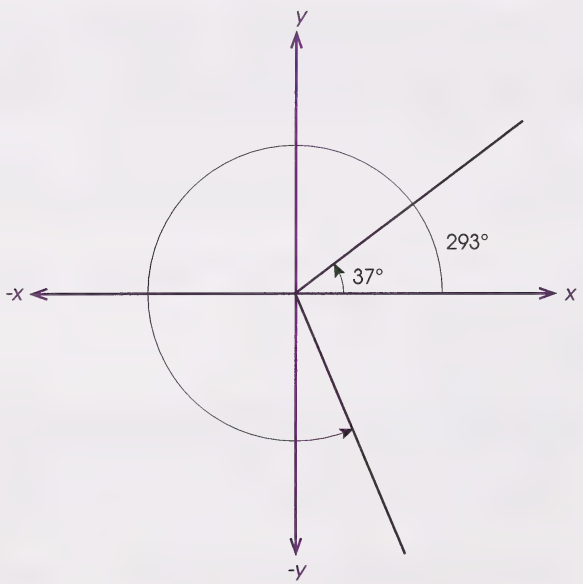
Check your answers by turning to the Appendix, Section 1: Activity 1.

In the previous question, although Myrna and Jaydn travelled different distances, the displacement was the same for both. This is because displacement (a vector quantity) depends on where the final position is from the initial position. Remember to always use units and assign a direction to a vector quantity. What would happen if your motion was at an angle?

There are different ways to measure the direction of a motion. Two common ways of representing direction are the method used in mathematics and the method used in navigation. In Science 20 you will use both methods, although the method used in mathematics will be used more extensively.

Mathematics Method

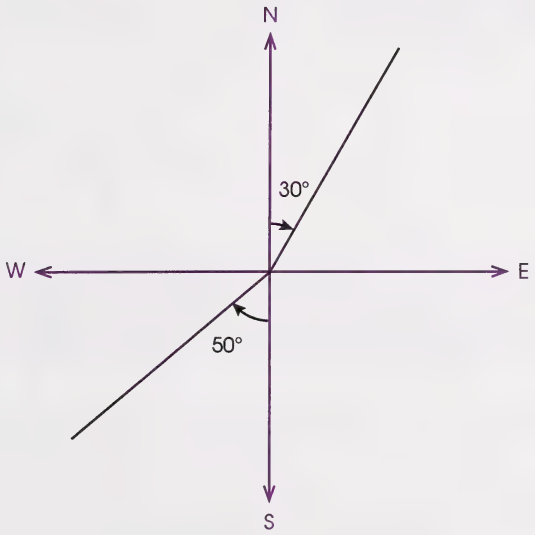
You are probably already familiar with how an angle is drawn on a coordinate plane in mathematics. To draw an angle on a coordinate plane, measure the angle counterclockwise from the x-axis (as shown in the following diagram). Recall that each quarter of the plane or quadrant is 90°.



Notice that both angles (37° and 293°) are measured counterclockwise from the x-axis. The angle of 293° is measured as 23° beyond 270° ($-y$-axis) since 270° + 23° = 293°. Mathematicians use this method to represent the location of a point on the coordinate plane in relation to the x- and y- axes. This allows them to represent the location of the point in terms of x and y. In Activity 2 you will represent vector quantities on a coordinate plane.

Navigation Method

When reading maps or using a compass you will see the direction given as N30°E or S50°W. These are read as 30° east of north and 50° west of south and are shown on the following directional axes. The directional axes are drawn with north (N) up, south (S) down, west (W) to the left, and east (E) to the right. The angles are read as west or east of north and west or east of south.



VISIONS

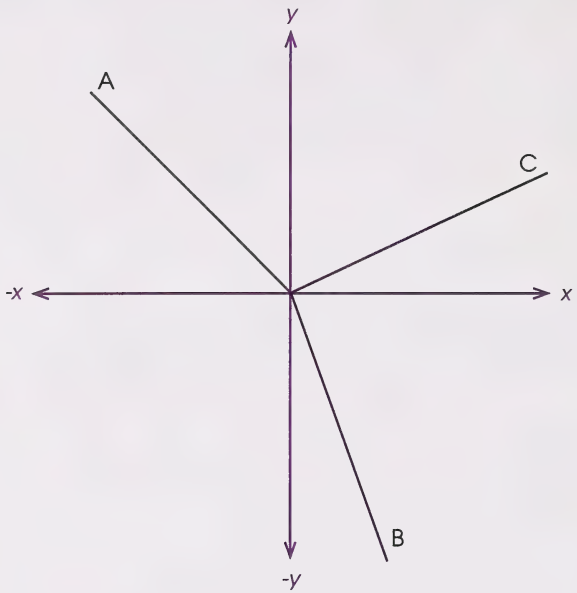
A second method used by navigators of ships and airplanes is given on pages 370 and 371 of *Visions* 2. In this method direction is measured clockwise from north. The angle is simply given as 75° or 234°, and is understood that it is measured clockwise from north. See diagram B in Figure 10.3 on page 371 of your textbook. This method will not be used for solving problems in this module.

An interesting aspect of this navigation method is that runways in most of Canada are numbered according to the heading on which the airplane is landing. Read page 371 of your textbook for information on how runways are numbered, and answer the following questions.

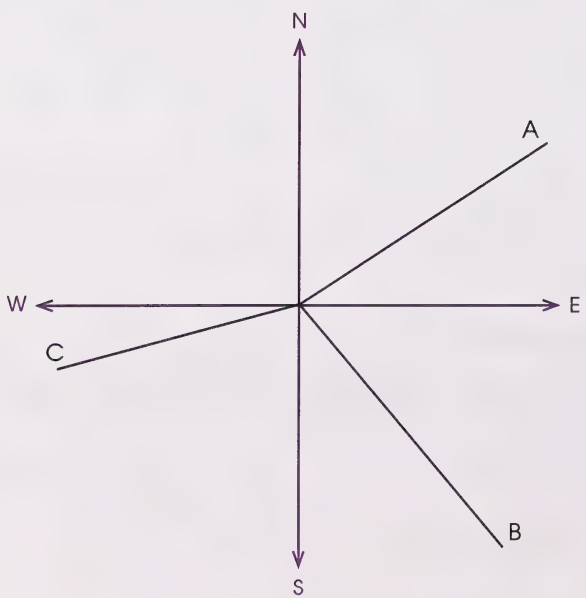
10. What is your heading if your are landing on a runway numbered 15?

11. What is the runway number on the opposite end of this runway?

12. Using a protractor, give the direction of the lines on the following coordinate plane. You may need to extend each of the lines or lay a ruler along the line on the surface of the protractor so you can read the angle on the protractor properly.



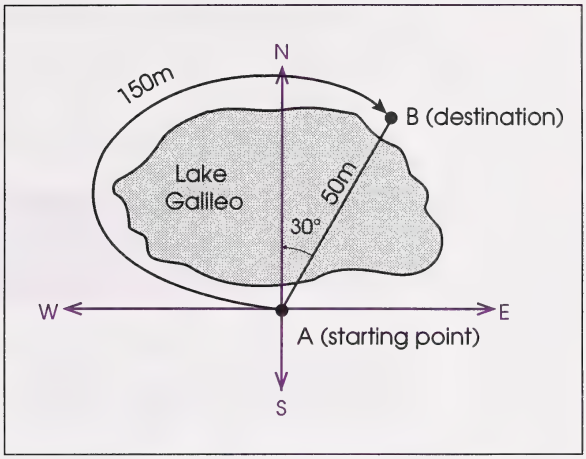
13. Give the direction of the lines on the following directional axis. Extend the lines if necessary.



14. Two people set out from A to reach B. Myrna walks around the lake, and Jaydn canoes across the lake. Both arrive at B at exactly the same time (150 s after starting).

    a. What are the distances travelled by Myrna and Jaydn?

    b. What are the displacements of Myrna and Jaydn?



Check your answers by turning to the Appendix, Section 1: Activity 1.

It is extremely important to use direction to distinguish a scalar quantity from a vector quantity (distance versus displacement). Why is direction so important? Another example of a scalar quantity is average speed (v_{ave}). The average speed of an airplane can be stated as 900 km/h, which only tells you magnitude. Is it important for an air traffic controller at an airport to know the magnitude of the speed of an incoming aircraft and its direction? When you describe how fast an object is travelling over a finite time interval and its direction, you are stating the average velocity of the object, a vector quantity $(\vec{v}_{ave})$.

TABLE 7.1 SUMMARY OF SCALAR AND VECTOR QUANTITIES

Scalar Quantities	Vector Quantities
• states magnitude only • Some examples are as follows: – distance (d) – change in distance (Δd) – average speed (v_{ave}) • Calculate average speed using the following: $v_{ave} = \frac{\Delta d}{\Delta t}$	• states magnitude and direction. • Some examples are as follows: – position $(\vec{d})$ – displacement $(\Delta\vec{d})$ – average velocity $(\vec{v}_{ave})$ • Calculate average velocity using the following: $\vec{v}_{ave} = \frac{\Delta\vec{d}}{\Delta t}$

15. Using the information and data from question 14, do the following questions.

    a. Calculate the average speeds of Myrna and Jaydn.

    b. Calculate the average velocities of Myrna and Jaydn.

Check your answers by turning to the Appendix, Section 1: Activity 1.

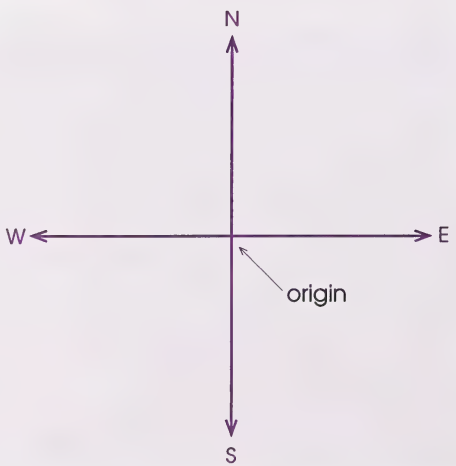
Thus far, you have learned that direction is essential in describing motion and scalar and vector quantities. In the next activity, you will apply this knowledge of direction to problem solving involving vectors.

Activity 2: Applications of Vectors

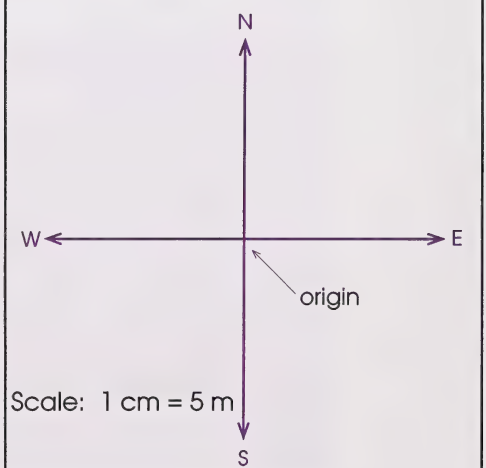
A sense of direction is not only important in distinguishing vector quantities from scalar quantities, but the use of vectors also provides a powerful mathematical tool for solving problems. In this activity, you will study how a vector arrow can replace any vector quantity; then you will use vector arrows to solve various vector situations.

First, you will learn to replace a vector quantity with a vector arrow. For example, suppos you walked 10 m north from a starting point. This is a displacement and is written as $\vec{d} = 10\ \text{m}$, north. To replace this vector quantity with a vector arrow, follow these steps.

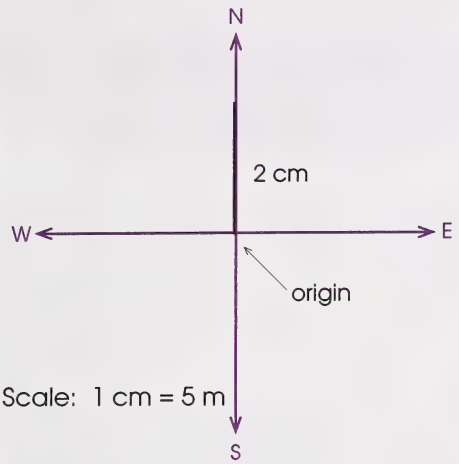
Step 1: Sketch a grid showing the origin and the directions.



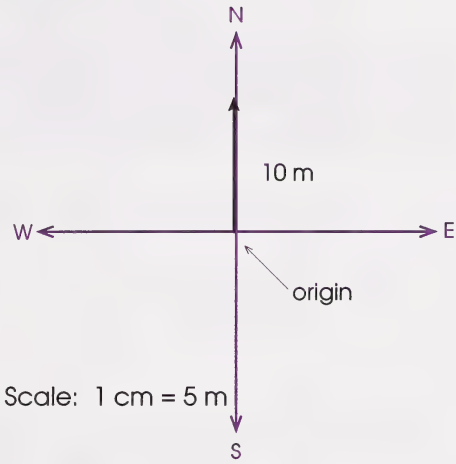
Step 2: Since you don't want to draw a line 10 m long, set up a scale.



Step 3: From the origin, draw a line 2 cm long in the direction of north to indicate a displacement of 10 m.



Step 4: Use an arrowhead to indicate that the direction is north.



Thus, a vector quantity $\left(\Delta\vec{d} = 10\text{ m, north}\right)$, which indicates magnitude (10 m) and direction (north), can be replaced by a vector arrow, which represents the same quantities.

1. Using the previous vector diagram as given in Step 4, answer the following questions.

   a. Which part of the vector diagram represents a magnitude of 10 m?

   b. Which part of the vector diagram represents a direction of north?

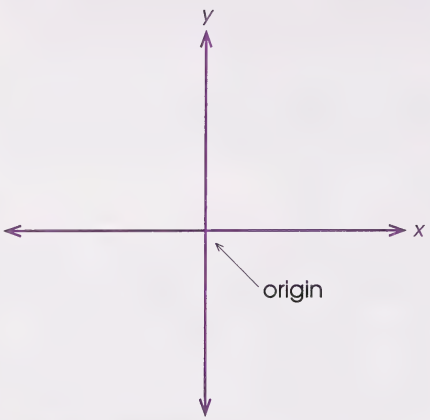
2. Draw a direction grid and use a scale of $1\text{ cm} = 5\text{ m}$ to draw vector arrows which represent the following vector quantities.

   - A – $\Delta\vec{d} = 15\text{ m}$, east
   - B – $\Delta\vec{d} = 20\text{ m}$, S40°W
   - C – $\Delta\vec{d} = 18\text{ m}$, N59°W

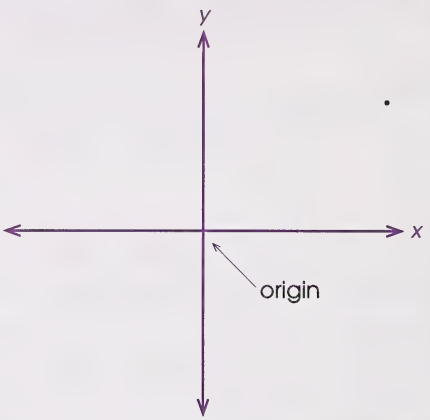
Check your answers by turning to the Appendix, Section 1: Activity 2.

Vectors can also be drawn on coordinate axes. For example, draw a vector that is 2.0 cm long at an angle of 35° from the *x*-axis.

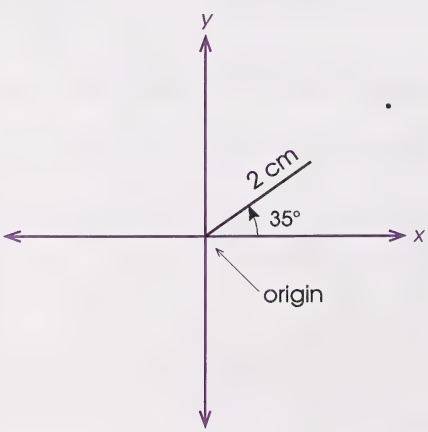
Step 1: Sketch a coordinate grid. Label the *x*-axis, the *y*-axis, and the origin.



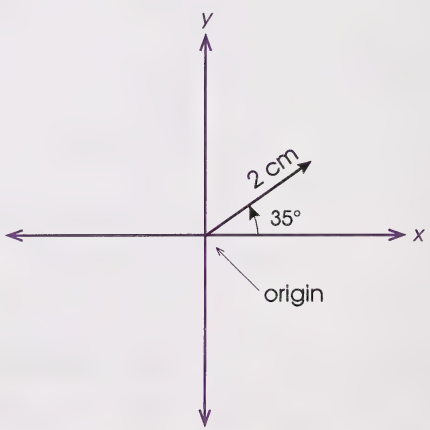
Step 2: Measure an angle of 35° from the *x*-axis, and make a dot on the outer edge of the protractor.



Step 3: From the origin, draw a line 2 cm long.



Step 4: Put an arrowhead on the end of the line to show the direction.



3. Draw vector arrows which represent the following quantities. Use a scale of 1 cm = 5 m.

   - A – 15 m, at an angle of 42° from the x-axis
   - B – 20 m, at an angle of 195° from the x-axis

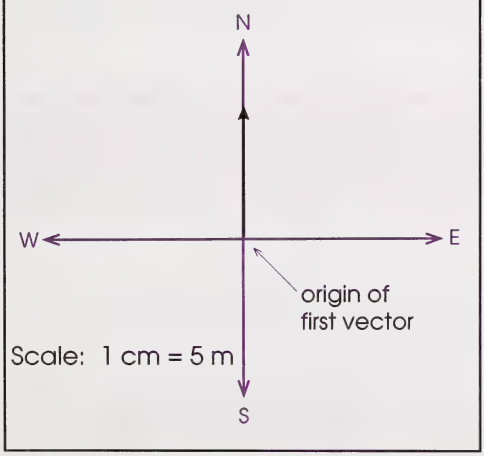
Check your answers by turning to the Appendix, Section 1: Activity 2.

Often, an object can experience two or more displacements in the same situation. These situations can occur with two or more vectors along the same line or at 180° to each other, two or more vectors at 90° to each other, or two or more vectors at any angle to each other. In this course you will analyse all of these situations with scale diagrams.

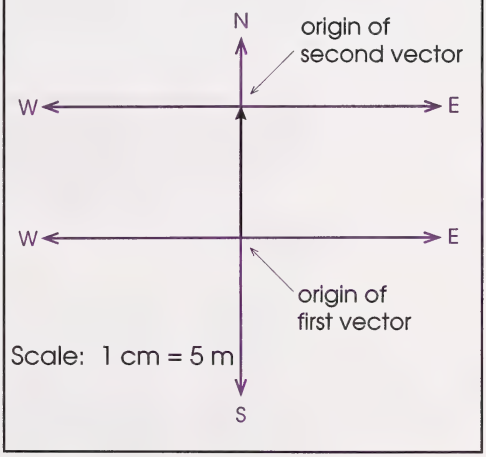
Situation 1

The situation involves two or more vectors along the same line or at 180° to each other. For example, a student walks 10 m north and then 15 m south. How would you draw vector arrows to describe the situation? Look at the following steps.

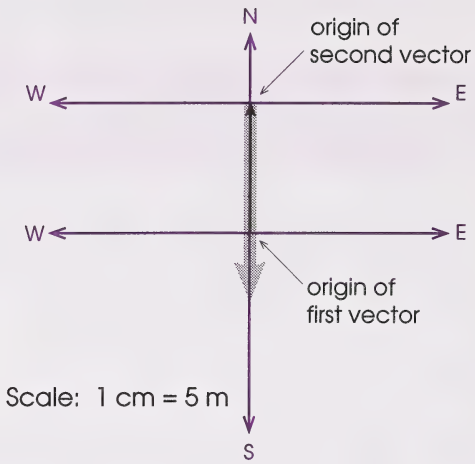
Step 1: First, draw a grid and choose an appropriate scale. Then draw a vector arrow displaying the first vector quantity.



Step 2: Since the origin for the second vector quantity is at the top of the last vector, sketch a new grid at this point.



Step 3: Draw a vector arrow from the new origin representing the second vector quantity. (Since it lies on top of the first vector, use a different colour or make it larger and shade it in.)



Situation 2

This situation involves two or more vectors at 90° to each other. Answer the following question concerning Situation 2.

4. A student walks 10 m north, and then walks 15 m east. Draw a vector diagram to display this situation using a scale of 1 cm = 5 m. Be sure to start the second vector at the end of the first vector.

Check your answers by turning to the Appendix, Section 1: Activity 2.

Situation 3

This situation involves two or more vectors at any other angle to each other. Answer the following question concerning Situation 3.

5. A student walks 10 m north, and then walks 15 m at an angle of 318° from the x-axis. Draw a vector diagram to display this situation using a scale of 1 cm = 5 m.

6. In review, what is the rule for drawing two vectors representing two displacements, one following the other.

Check your answers by turning to the Appendix, Section 1: Activity 2.

esultant – the ingle vector that as the same ffect as two or nore individual ectors

The purpose of drawing vectors to represent a situation is not only to aid you in visualizing the situation, but it will also help you in solving the problem.

The problem in all these situations is to find the resulting displacement from a starting point, or the net displacement from a starting point, or the **resultant** (given the symbol $\vec{R}$). They all mean the same thing.

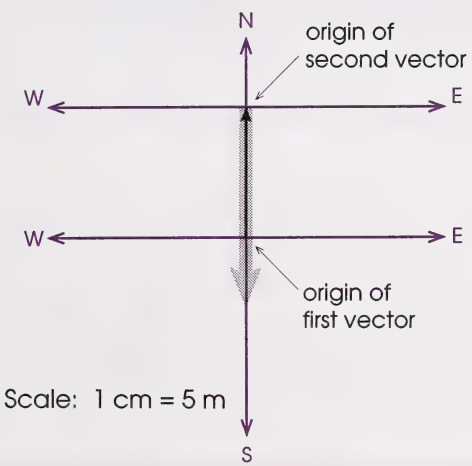
VISIONS

Read the section entitled Vectors Can Be Added on pages 371 and 372 and the last paragraph on page 375 in your textbook; then answer the following two questions.

7. What is the name of the rule used whenever vectors in the same situation are added?

8. What is the rule for vector addition?

9. In Situation 1, with two or more vectors at 180° to each other, the vector diagram was as follows:



a. Sketch the resultant displacement $\left(\Delta\vec{d}_R\right)$.

b. What is the resultant displacement $\left(\Delta\vec{d}_R\right)$?

$\Delta\vec{d}_R$ = _____, _____

↑ Measure the length of your resultant vector using a ruler, and calculate your answer using your scale.

↑ State the angle the resultant vector is pointing. (Use a protractor to measure the angle, if necessary.)

10. Go back to question 4 in this activity and answer the following questions.

    a. Draw the resultant vector on the diagram.

    b. What is the $\Delta\vec{d}_R$? Measure the resultant to the nearest tenth of a centimetre.

11. Go back to question 5 in this activity and answer the following questions.

    a. Draw the resultant vector on the diagram.

    b. What is the $\Delta\vec{d}_R$? Measure the resultant to the nearest tenth of a centimetre.

VISIONS

12. Study the Practice Problems on pages 372 to 373 of *Visions 2*; then do problems 1 and 5 on pages 373 and 374. Use a coordinate plane for these problems. Compare the resultants in problems 1 and 5. What similarity do you see?

Study the Practice Problems on pages 374 to 376 of *Visions 2*; then do the following questions.

13. In order to avoid a severe storm at sea, a ship is set to sail 200 km at an angle of N40°E, then 150 km at an angle of S60°E. What is the displacement of the ship?

14. Imagine the corner of a soccer field as the origin of the (x, y)-coordinate system. During a soccer game, player A kicks the ball from the origin 10.0 m at an angle of 23° from the x-axis; player B then kicks the ball 6.0 m at an angle of 125°; and finally, player C kicks the ball 8.0 m at an angle of 30° from x. What is the displacement of the ball?

Check your answers by turning to the Appendix, Section 1: Activity 2.

The use of vector diagrams drawn to scale and the rule for vector addition can solve any vector situation.

In all the previous questions you used vector quantities called displacements; but these methods can also be used to solve for the resultant of any vector. Another vector quantity is velocity $(\vec{v})$. You can use the methods you have studied for velocity vectors. Do the following questions to solve for the resultant velocity using scale diagrams. Let 1 cm represent 1.0 m/s.

15. A dog that can swim at 1.0 m/s jumps in a river that is flowing 3.0 m/s, east.

    a. Solve for the resultant velocity $(\vec{v}_R)$ of the dog if the dog heads upstream (west). Is the dog getting ahead?

    b. Solve for the resultant velocity vector $(\vec{v}_R)$ of the dog if he heads north. What direction is the dog actually heading?

16. A dog that can swim at 1.0 m/s jumps in a river that is flowing 3.0 m/s at an angle of N60°E. Solve for the resultant velocity vector $(\vec{v}_R)$ of the dog if he heads north. What direction is the dog actually heading?

Check your answers by turning to the Appendix, Section 1: Activity 2.

Thus far, you have learned how vectors and the use of direction can be used in problem solving. In the next activity, you will see how direction is used in a graphical analysis of motion.

Activity 3: Graphing Revisited

Developing a sense of direction in analysing motion is not only important in distinguishing scalar quantities from vector quantities, but it is also important in a mathematical analysis of motion using formulas.

In this activity, you will revisit graphing (another powerful tool for analysing motion), and you will discover how direction adds a useful feature to the graph. Graphing is important because it not only yields all the same answers that problem solving using formulas can, but it also helps you visualize the motion.

In Science 10 you studied the graphs of an object moving at uniform motion in one direction only. Can you remember what these graphs looked like and how to interpret them? Investigate this simple type of motion again to review all the rules necessary for graphical analysis of motion.

Science Skills

- ☐ A. Initiating
- ☑ B. Collecting
- ☑ C. Organizing
- ☑ D. Analysing
- ☐ E. Synthesizing
- ☐ F. Evaluating

Investigation: Uniform Motion – Review

Follow the directions of this investigation carefully. Pay special attention to the required components and applied science skills.

Purpose

Investigate uniform motion in one direction only using graphical analysis.

Background Information

VISIONS

Review Skill 14 on page 538 of your textbook to review rules on graphing. Review Appendix C on page 544 of *Visions 2* as well to review significant digits. The results of an investigation you performed in Science 10 on uniform motion are provided in the Observations section. Study the results on the ticker tape carefully.

Materials

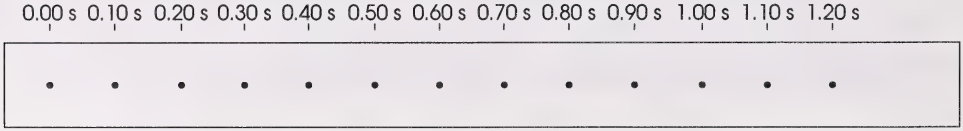
- ticker tape results (given in Observations section)
- ruler (given in Appendix)
- graph paper

Procedure

Step 1: Using the cut out ruler from the end of the Appendix or your own centimetre ruler, measure the distances travelled after 0.10 s, 0.20 s, 0.30 s, and so on by measuring to the centre of the appropriate dots. The first five measurements are done for you. Make your measurements to the nearest tenth of a millimetre. (Estimate the last digit.)

Step 2: Record the results by making and completing a chart like the one in the Observations section.

Observations



1. Make and complete a chart like the following.

Time (s)	Distance (mm)	Time (s)	Distance (mm)
0.00	0.00	0.70	
0.10	10.0	0.80	
0.20	20.2	0.90	
0.30	29.8	1.00	
0.40	39.8	1.10	
0.50	50.0	1.20	
0.60			

2. Using graph paper, draw a graph of distance versus time. Be sure to label the axes and give the graph a title.

Analysis and Interpretation

3. What characteristic of the previous graph indicates that the object is travelling at uniform motion?

4. How can the graph be used to calculate the average speed of the object?

5. What is the formula for determining the slope of a graph?

6. When you find the slope of the graph, you are finding the average speed during a specified time interval.

   a. Calculate the slope of the entire graph from $t = 0.0$ s to $t = 1.2$ s. This slope determines the average speed of the entire trip.

   b. When you find the slope of the graph for a small time interval, you are finding the average speed during that small time interval only. Calculate the slopes of the graph you drew for question 2 for each time interval (0.00 – 0.10 s, 0.10 s – 0.20 s, and so on) and complete the following chart. The first five are done for you. Use the values from the graph for each interval, not the values from the table. The purpose of using values from the graph is that these values will help average out errors in measurement.

Note: Since the time interval is between 0.00 s and 0.10 s, the calculated slope is the average for that time interval and is recorded between these two values.

Time (s)	Slope (mm/s)	Time (s)	Slope (mm/s)
0.00		0.60	
	100 or 1.0×10^2		
0.10		0.70	
	100 or 1.0×10^2		
0.20		0.80	
	100 or 1.0×10^2		
0.30		0.90	
	100 or 1.0×10^2		
0.40		1.00	
	100 or 1.0×10^2		
0.50		1.10	
0.60		1.20	

The following are sample calculations for the first three intervals.

Time Interval	Calculation
0.00 s to 0.10 s	$\frac{10\text{ mm} - 0\text{ mm}}{0.10\text{ s} - 0.00\text{ s}} = \frac{10\text{ mm}}{0.10\text{ s}}$ $= 100\text{ mm/s}$
0.10 s to 0.20 s	$\frac{20\text{ mm} - 10\text{ mm}}{0.20\text{ s} - 0.10\text{ s}} = \frac{10\text{ mm}}{0.10\text{ s}}$ $= 100\text{ mm/s}$
0.20 s to 0.30 s	$\frac{30\text{ mm} - 20\text{ mm}}{0.30\text{ s} - 0.20\text{ s}} = \frac{10\text{ mm}}{0.10\text{ s}}$ $= 100\text{ mm/s}$

Note: The values used to calculate the slope have been read from the graph. Since slope really determines average speed, these values could represent average speed.

7. Draw a graph of average speed (or slope) versus time. Plot the average of the two time intervals used. For example, the average of the fist two time intervals (0.00 s and 0.10 s) is 0.05.

8. Determine the slope of this graph. (Be aware of the units being used.)

9. What does this value represent?

10. What value does the y-intercept indicate?

11. What value does the area under the line of the graph determine?

12. Calculate the total change in distance in 1.20 s using the area under the line of the graph method.

13. Was there anything in these graphs that indicates the direction the object is moving?

Check your answers by turning to the Appendix, Section 1: Activity 3.

Now that you have reviewed how to graph uniform motion, you will study the effect of direction on graphing. To discover the effect of direction on graphing, do the following investigation.

Science Skills
- A. Initiating
- B. Collecting
- C. Organizing
- D. Analysing
- E. Synthesizing
- F. Evaluating

Investigation: Uniform Motion in Two Directions

Follow the directions of this investigation carefully. Pay special attention to the required components and applied science skills.

Purpose

Study the motion of an object travelling at uniform motion in two directions using a graphical analysis.

Background Information

The Observations section has a diagrammatic representation of strobescopic photographs of a billiard ball moving at a uniform speed in one direction then bouncing off a cushion and travelling at a uniform speed in the opposite direction.

The photographs are taken 0.10 s apart. The white balls with the dot in the centre indicate motion to the cushion, and the coloured balls indicate motion after rebounding off the cushion. Call the motion to the cushion motion to the right, and the motion away from the cushion motion to the left. Study the diagram in the Observations section.

Materials

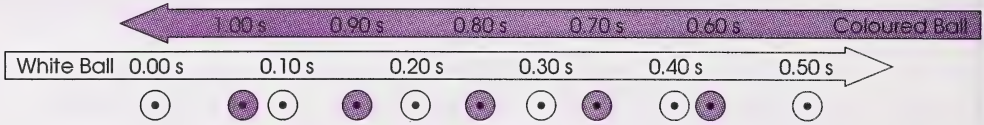
- diagrammatic representation of photographs of a moving billiard ball
- ruler (given in Appendix)
- graph paper

Procedure

Step 1: Measure the distances the ball travelled after 0.00 s, 0.10 s, 0.20 s, and so on by measuring the distances from the starting position (centre of the first ball) to the centre of each other ball. The first four measurements are done for you. Make your measurements to the nearest tenth of a millimetre.

Step 2: Record these results by making and completing a chart like the one in the Observations section.

Observations



14. Make and complete a chart like the following by taking measurements from the photograph. Right is written as positive, and left is written as negative. (Make measurements to the centre of the balls).

Time (s)	Position (mm)	Time (s)	Position (mm)
0.00	0.00	0.60	
0.10	19.5	0.70	
0.20	40.0	0.80	
0.30	59.5	0.90	
0.40		1.00	
0.50			

15. Using graph paper, draw a graph of position versus time.

16. Calculate the slopes of all the time intervals of the graph in question 15 using the values read from the graph. Record the slopes as velocities in the following chart. The first three are done for you. Subtract each recorded position from the preceding one at the given time interval. Note that velocity is used now because direction is considered. You can use each of these changes in position as displacements because the starting position is zero.

Time (s)	Average Velocity (mm/s)	Time (s)	Average Velocity (mm/s)
0.00	200, right	0.50	
0.10	200, right	0.60	
0.20	200, right	0.70	
0.30		0.80	
0.40		0.90	
0.50		1.00	

The following are calculations for the first three velocities. Values are read from the graph.

Time Interval	Calculation
0.00 s to 0.10 s	$\frac{20\text{ mm} - 0\text{ mm}}{0.10\text{ s} - 0.00\text{ s}} = \frac{20\text{ mm}}{0.10\text{ s}}$ $= 200\text{ mm/s}$
0.10 s to 0.20 s	$\frac{40\text{ mm} - 20\text{ mm}}{0.20\text{ s} - 0.10\text{ s}} = \frac{20\text{ mm}}{0.10\text{ s}}$ $= 200\text{ mm/s}$
0.20 s to 0.30 s	$\frac{60\text{ mm} - 40\text{ mm}}{0.30\text{ s} - 0.20\text{ s}} = \frac{20\text{ mm}}{0.10\text{ s}}$ $= 200\text{ mm/s}$

17. Draw a graph of average velocity versus time.

Analysis and Interpretation

18. Calculate the slope of the graph from $t = 0.00$ s to $t = 0.50$ s. (Use values from the graph, not points from the table.)

19. Calculate the slope of the graph from $t = 0.50$ s to $t = 1.00$ s. (Use values from the graph, not points from the table.)

20. What does this indicate about the motion?

21. What was the difference in the graph between $t = 0.00$ s to $t = 0.50$ s and $t = 0.60$ s to $t = 1.00$ s?

22. What is the area under the line between $t = 0.00$ s and $t = 0.50$ s? What does this area determine?

23. What is the area under the line between $t = 0.50$ s to $t = 1.00$ s?

24. What was the net displacement after 1.00 s? What does this net displacement indicate?

Check your answers by turning to the Appendix, Section 1: Activity 3.

Notice that in questions 22 and 23 in Section 1, Activity 3 the symbol $\Delta\vec{d}$ was used. The area under the velocity time graph determines displacement. You have now completed a study of direction and its effect on graphing.

Follow-up Activities

If you had difficulties understanding the concepts in the activities, it is recommended that you do the Extra Help. If you have a clear understanding of the concepts, it is recommended that you do the Enrichment.

Extra Help

Do the following questions to review important concepts from Section 1.

1. All quantities in physics may be classified as either vector or scalar quantities. What is the main difference between a scalar quantity and a vector quantity?

2. State whether the following terms and phrases represent a vector quantity or a scalar quantity.

   a. represents magnitude only
   b. represents magnitude and direction
   c. represented by a "-" notation
   d. distance
   e. position
   f. change in distance
   g. change in position
   h. displacement
   i. Δd
   j. $\Delta\vec{d}$
   k. average speed
   l. average velocity
   m. $\frac{\Delta d}{\Delta t}$
   n. $\frac{\Delta\vec{d}}{\Delta t}$

3. Match the following descriptions with the appropriate symbols listed. Place the symbol by the description in the space provided.

- d
- $\vec{d}$
- v_{ave}
- $\vec{v}_{ave}$
- Δd
- $\Delta \vec{d}$

_____ a. average velocity

_____ b. displacement

_____ c. position

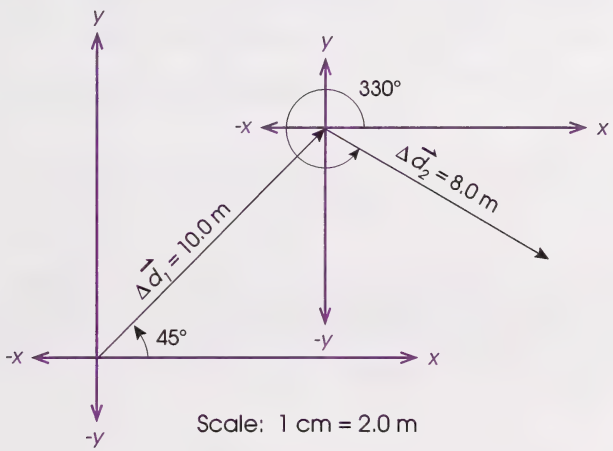
_____ d. distance

_____ e. change in distance

_____ f. average speed

4. Draw vector representing $\Delta \vec{d} = 20\text{ m}, 235°$ from the x-axis using a scale of $1\text{ cm} = 5\text{ m}$.

5. Given the following vector situation of two displacement vectors, draw the resultant vector on the diagram and measure the magnitude and direction of the resultant. Use a ruler and a protractor.



6. You studied two types of graphs in uniform motion: a position-time graph and a velocity-time graph. You can also call a position-time graph a displacement-time graph when the starting position is zero.

   a. For uniform motion, will the graph in a displacement-time graph be a straight line or a curve?

   b. In a position-time graph, what value will the slope of the line determine?

   c. For uniform motion, what is the slope of the line in a velocity-time graph?

   d. What does the area under the line of a velocity-time graph determine?

e. What additional feature does motion in two directions add to the following?

i. position-time graph

ii. a velocity-time graph

Check your answers by turning to the Appendix, Section 1: Extra Help.

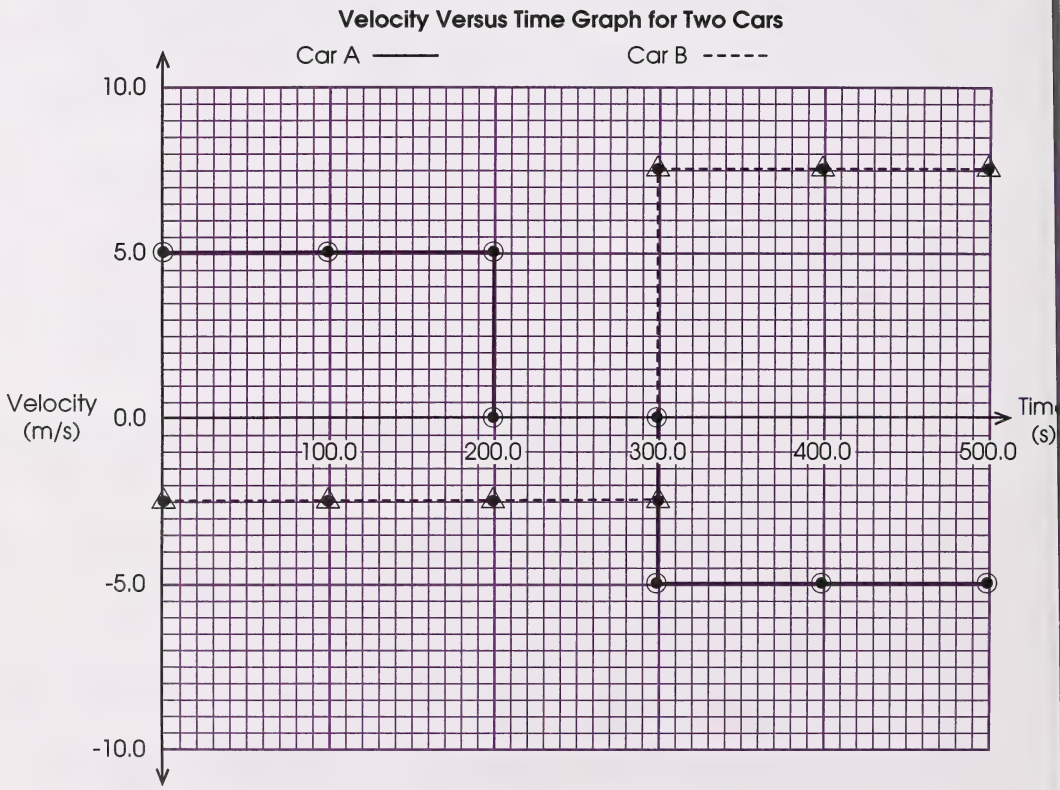
Enrichment

You should now be able to use your understanding of the concepts from Section 1 to answer the following questions.

VISIONS

1. Do textbook question 5 on page 377 using a scale drawing to determine the resultant.

2. The following is a graph depicting the velocities of two cars (A and B) that start from the same reference point. Use the graph and the concepts you have studied in this section to find the position where Cars A and B meet again and at what time.



To help you solve this question, follow these steps.

Step 1: Calculate the area between the line for each car and the horixontal axis for each value on the time axis; then complete the following charts.

DISPLACEMENT VERSUS TIME FOR CAR A	
Time (s)	Displacement (m)

DISPLACEMENT VERSUS TIME FOR CAR B	
Time (s)	Displacement (m)

Step 2: Plot a displacement-time graph for Cars A and B on graph paper. Label the axes appropriately. Use this graph to find the position where Cars A and B meet again and at what time.

Check your answers by turning to the Appendix, Section 1: Enrichment.

Conclusion

You have now completed Section 1 and have investigated how direction is important in a study of the simplest type of motion – uniform motion. You were able to depict motion in any direction and were able to solve problems using vectors and scale drawings. Finally, you were able to analyse motion in any direction using graphing. In the next section, you will investigate how direction will affect a more complicated type of motion – accelerated motion.

ASSIGNMENT

Turn to your Assignment Booklet and do the assignment for Section 1.

Section

2 Accelerated Motion



Imagine yourself sitting in an airplane preparing for takeoff. You feel a rush of adrenalin in your body as you anticipate what will happen in the next few moments. Suddenly, you feel the plane thrust forward, and in a span of a few seconds, the plane has gone from rest to a speed of about 200 km/h (necessary to achieve takeoff). What type of motion would you experience?

VISIONS

Imagine yourself in the Drop of Doom at West Edmonton Mall. (See the photograph on page 432 of *Visions 2*.) Can you imagine the same anticipated rush as the warning light flashes and the cage suddenly drops? What type of motion would you experience here?

In the previous section you studied one type of motion – uniform motion. You used vectors in a mathematical and graphical analysis to determine that one factor that identifies different types of motion is **direction**. This enabled you to identify two other types of motion – uniform speed and uniform velocity.

If you analyse the motion of the jet and the Drop of Doom, what is the factor that distinguishes these two motions from uniform motion? Do they appear to be changing their velocities? When an object changes its velocity, it is said to be accelerating. Accelerating includes both increasing velocity and decreasing velocity.

In this section you will identify what accelerated motion is; then you will analyse accelerated motion graphically and mathematically. You will also conduct an investigation to study the simplest type of uniform acceleration called the acceleration due to free fall, or the acceleration of falling bodies.

Activity 1: What Is Acceleration?

You have all experienced or heard of the term acceleration, but what exactly is this type of motion? What determining factor sets accelerated motion apart from uniform motion? The following investigation will help you identify the fundamental difference between uniform motion and accelerated motion.

cience Skills

A. Initiating
B. Collecting
C. Organizing
D. Analysing
E. Synthesizing
F. Evaluating

Investigation: Identifying Accelerated Motion

Follow the directions of this investigation carefully. Pay special attention to the required components, safety aspects, and applied science skills.

Purpose

Investigate the motion of an object rolling down a slanted table and to identify the factor that distinguishes this type of motion from uniform motion.

Background Information

1. State a hypothesis as to identifying the factor that distinguishes the motion of a steel ball rolling down a slanted table from uniform motion.

Materials

- audiotape (beeps 1 s apart)
- long, smooth table or a sheet of smooth plywood (about 2 m in length)
- small steel ball
- computer paper (about 2 m in length)
- ruler or metre stick
- felt pen or pencil

Procedure

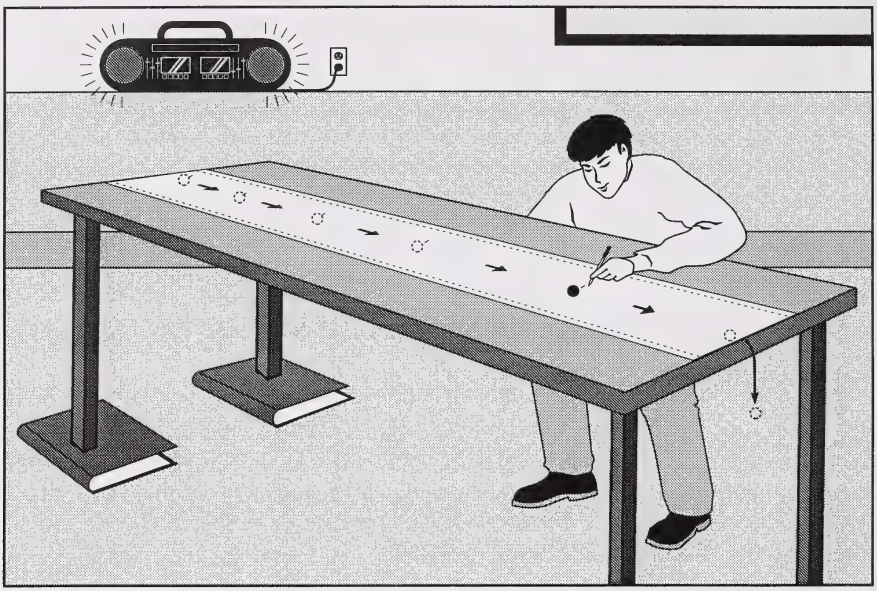
Step 1: Set up the apparatus as shown in the diagram in Step 5. Set your tape player at the start of the beeps that are one second apart. These are the second two minute set on the audiotape. You may find it useful to listen to the first three beeps to get a sense of timing for when each beep occurs.

Step 2: Hold the steel ball at the top of the table and carefully listen to the audiotape for the beeps.

Step 3: Mark the starting position of the steel ball by placing a mark on the paper with a felt pen. (Mark the position of the centre of the steel ball and label this mark 0 s.)

Step 4: On the exact start of a beep, release the steel ball, allowing it to roll down the table.

Step 5: Follow the steel ball down the table, marking the position of the centre of the ball every time you hear a beep. Continue this down the length of the table, obtaining at least five marks on the paper after the start position. (You might have to adjust the height of one end of the table until you can achieve these results.)



Step 6: From the starting point, label these marks 0 s, 1 s, 2 s, 3 s, 4 s, and 5 s successively.

Step 7: Use a ruler or metre stick to measure the distances from 0 s to 1 s, 0 s to 2 s, 0 s to 3 s, and so on. (Measurements should be in centimetres to one decimal place.)

Step 8: Make a chart like the one in the Observations section to record your values.

Observations

2. What was the manipulated variable in this experiment?

3. What was the responding variable in this experiment?

4. Complete the chart by recording the distances you measure in Step 7.

Time (s)	Position (cm)	Time (s)	Position (cm)
0		3	
1		4	
2		5	

Analysis and Interpretation

5. How does the spacing of the marks for the rolling ball in this investigation compare with the spacing of the marks for an object moving with uniform motion as observed in the investigation in Section 1, Activity 3?

6. What does the spacing of the marks in this investigation indicate about the motion of the steel ball rolling down the table? (Hint: Since $\vec{v}_{ave} = \frac{\Delta \vec{d}}{\Delta t}$, what is happening to the velocity of the steel ball between each successive time interval?)

7. From your previous studies of motion in Science 10, what is the name given to describe the motion of an object that is changing its velocity in a time interval?

8. Draw a graph of the data for this investigation. (Remember to put time on the horizontal axis.)

9. How does the graph of a rolling ball in this investigation compare with the graph of an object moving with uniform motion, as in the investigation in Section 1, Activity 3?

10. From your previous studies of motion in Science 10 and in Section 1 of this module, what does the slope of the line in a position-time graph determine?

11. Study your graph of a rolling ball in this investigation. What appears to be happening to the slope of the line?

12. Based on questions 10 and 11, what appears to be happening to the motion of the ball in this investigation?

Check your answers by turning to the Appendix, Section 2: Activity 1.

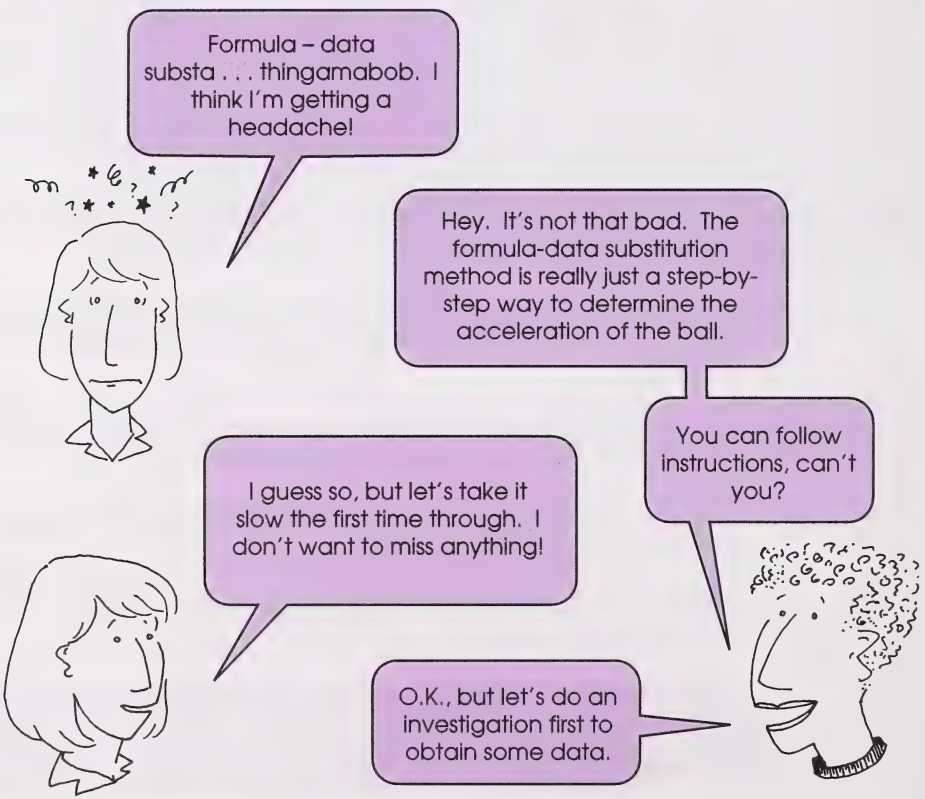
Through an analysis of the spacing of the marks and a careful observation of the graph, you learned that the velocity of the rolling steel ball is changing at a regular rate. Specifically, the velocity of the rolling steel ball seems to be speeding up. This is another type of motion called **uniformly accelerated motion**. In the next activity, you will analyse this type of motion more quantitatively.

uniformly accelerated motion – motion of an object that is changing its velocity during a time interval

Activity 2: Mathematical Analysis of Uniformly Accelerated Motion

In the previous activity you obtained results of an object moving with uniformly accelerated motion. To analyse this type of motion more quantitatively, you can analyse the data using two different mathematical methods. One method is a formula-data substitution method and the other is a graphical method.

In this activity, you will analyse accelerated motion using the formula-data substitution method.



Science Skills

- ☐ A. Initiating
- ☐ B. Collecting
- ☐ C. Organizing
- ☑ D. Analysing
- ☐ E. Synthesizing
- ☐ F. Evaluating

Investigation: Mathematical Analysis of Uniformly Accelerated Motion (Using Given Data)

Follow the directions of this investigation carefully. Pay special attention to the required components and applied science skills.

Purpose

Analyse the data from an investigation involving a ball rolling down a slanted table using the formula-data substitution method.

Materials

- data chart provided in the Procedure section or your own results from the investigation in Activity 1
- graph paper

Procedure

The following chart displays the results of the same investigation you performed in Activity 1. The investigation was done by a student using a similar apparatus. If you obtained good results for the investigation in Activity 1, you may use those results instead of the given data. Compare your charts and graphs with the answers in the Appendix.

Time (s)	Position (cm)
0.0	0.0
1.0	8.1
2.0	31.9
3.0	72.0
4.0	128.1
5.0	199.1

Step 1: Recall that the average velocity during a time interval can be calculated using $\vec{v}_{ave} = \frac{\Delta \vec{d}}{\Delta t}$. Calculate the average velocity during each 1.0 s interval.

Step 2: Construct a chart like the one in the Observation section.

Observations

1. Complete the following chart. The first two calculations are done for you.

Time (s)	Average Velocity (cm/s)
0.0	
	8.1
1.0	
	23.8
2.0	
3.0	
4.0	
5.0	

Note: If the average velocity ($\vec{v}_{ave}$) is determined during a time interval, it must be noted that this is an average velocity and that the value of $\vec{v}_{ave}$ is placed between the two times.

Note: Since the direction in all $\vec{v}_{ave}$ is considered to be down the table on which the ball was rolling, the direction for $\vec{v}_{ave}$ has been omitted for all calculations.

Calculation 1

Calculate $\vec{v}_{ave}$ during the first time interval (t = 0.0 s to t = 1.0 s).

The solution is as follows:

Calculate Δt and $\Delta\vec{d}$.

$$\Delta t = t_{final} - t_{initial}$$
$$= 1.0\,\text{s} - 0.0\,\text{s}$$
$$= 1.0\,\text{s}$$

(This can be abbreviated as $t_f - t_i$.)

$$\Delta\vec{d} = \Delta\vec{d}_f - \Delta\vec{d}_i$$
$$= 8.1\,\text{cm} - 0.0\,\text{cm}$$
$$= 8.1\,\text{cm}$$

($\Delta\vec{d}$ is the displacement in each time interval.)

Calculate $\vec{v}_{ave}$.

$$\vec{v}_{ave} = \frac{\Delta\vec{d}}{\Delta t}$$
$$= \frac{8.1\,\text{cm}}{1.0\,\text{s}}$$
$$= 8.1\,\text{cm/s} \text{ (2 significant digits)}$$

Note: In your final answer, use the significant digits of your measured quantity $\left(\Delta\vec{d}\right)$ and not time, since time was set by a machine and the number of significant digits is unknown. Notice when we put the unit for displacement (cm) and the unit for time (s) into the formula for velocity we get cm/s, which is the unit for velocity.

Calculation 2

Calculate $\vec{v}_{ave}$ during the second time interval (t = 1.0 s to t = 2.0 s).

The solution is as follows:

Calculate Δt and $\Delta\vec{d}$.

$$\Delta t = t_f - t_i$$
$$= 2.0\,\text{s} - 1.0\,\text{s}$$
$$= 1.0\,\text{s}$$

$$\Delta\vec{d} = \Delta\vec{d}_f - \Delta\vec{d}_i$$
$$= 31.9\,\text{cm} - 8.1\,\text{cm}$$
$$= 23.8\,\text{cm}$$

Calculate $\vec{v}_{ave}$.

$$\vec{v}_{ave} = \frac{\Delta\vec{d}}{\Delta t}$$
$$= \frac{23.8\,\text{cm}}{1.0\,\text{s}}$$
$$= 23.8\,\text{cm/s} \quad \text{(3 significant digits)}$$

Analysis and Interpretation

2. If the calculated average velocity between t = 0.0 s and t = 1.0 s is 8.1 cm/s and if you also know that the ball is speeding up, use this information to answer the following questions.

   a. Is the ball travelling faster or slower than 8.1 cm/s at the exact time of t = 0.0 s?

   b. Is the ball travelling faster or slower than 8.1 cm/s at the exact time of t = 1.0 s?

   c. At what exact time do you think the ball is travelling at exactly 8.1 cm/s?

Check your answers by turning to the Appendix, Section 2: Activity 2.

nstantaneous velocity – ndicates the xact velocity at an exact point in ime

In Section 1, average velocity was defined as velocity calculated over a finite time interval. Question 2 identifies another important type of velocity called **instantaneous velocity**, which differs greatly from average velocity. Look at the following table.

TABLE 7.2 CHARACTERISTICS OF AVERAGE AND INSTANTANEOUS VELOCITY

Average Velocity	Instantaneous Velocity
• indicates the average velocity during a **time interval**	• indicates the exact velocity at an **exact time** indicated
• symbol is $\vec{v}_{ave}$	• symbol is $\vec{v}$
• Example: The average velocity between $t = 0.0$ s and $t = 1.0$ s is 8.1 cm/s, written as $\vec{v}_{ave} = 8.1\,\text{cm/s}$.	• Example: The instantaneous velocity at the exact time of $t = 0.5$ s is exactly 8.1 cm/s, written as $\vec{v}_{0.5\,s} = 8.1\,\text{cm/s}$. Note: $\vec{v}_{0.5\,s}$ is read as "the instantaneous velocity at $t = 0.5$ s."

3. If you are driving your car north to Edmonton and you glance at your speedometer and notice that you are travelling at 100 km/h, is this quantity an average velocity or an instantaneous velocity?

4. What is the value of your velocity?

5. If you drove your car north to Edmonton, a displacement of 200.0 km in 2.10 h, what was your average velocity?

Check your answers by turning to the Appendix, Section 2: Activity 2.

Using data from the previous investigation, try to determine the instantaneous velocities at the given times of $t = 0.0$ s, 1.0 s, 2.0 s, and so on. The instantaneous velocity at $t = 0.0$ s is easy since you know that the object was at rest. Therefore, $\vec{v}_{0.0\,s} = 0.0\,\text{cm/s}$. How can you calculate the instantaneous velocity at $t = 1.0$ s if the only other known fact is that the average velocity between $t = 0.0$ s and $t = 1.0$ s was 8.1 cm/s? Another formula to calculate average velocity using instantaneous velocities is as follows:

initial instantaneous velocity final instantaneous velocity

$$\vec{v}_{ave} = \frac{\vec{v}_i + \vec{v}_f}{2}$$

average velocity

6. Use the previous formula to calculate the instantaneous velocities at $\vec{v}_{0.0\,s}$, $\vec{v}_{1.0\,s}$, $\vec{v}_{2.0\,s}$, and so on up to $\vec{v}_{5.0\,s}$. Construct and complete the following chart. The first three calculations are done for you.

Time (s)	Instantaneous Velocity (cm/s)
0.0	0.0
1.0	16.2
2.0	31.4
3.0	
4.0	
5.0	

Calculation 1

Find $\vec{v}_{0.0\,s}$.

Since the ball was at rest at $t = 0.0$ s, $\vec{v}_{0.0\,s} = 0.0$ cm/s.

Calculation 2

Find $\vec{v}_{1.0\,s}$.

The data is as follows:

$\vec{v}_i = 0.0$ cm/s at $t = 0.0$ s
$\vec{v}_{ave} = 8.1$ cm/s ($t = 0.0$ s to $t = 1.0$ s)

The solution is as follows:

$$\vec{v}_{ave} = \frac{\vec{v}_i + \vec{v}_f}{2}$$
$$\vec{v}_f = 2\vec{v}_{ave} - \vec{v}_i$$
$$= (2 \times 8.1\,\text{cm/s}) - 0.0\,\text{cm/s}$$
$$= 16.2\,\text{cm/s}$$

Therefore, $\vec{v}_f = \vec{v}_{1.0\,s} = 16.2$ cm/s.

Calculation 3

Find $\vec{v}_{2.0\,s}$.

The data is as follows:

$\vec{v}_i = 16.2$ cm/s at $t = 1.0$ s
$\vec{v}_{ave} = 23.8$ cm/s ($t = 1.0$ s to $t = 2.0$ s)

The solution is as follows:

$$\vec{v}_{ave} = \frac{\vec{v}_i + \vec{v}_f}{2}$$
$$\vec{v}_f = 2\vec{v}_{ave} - \vec{v}_i$$
$$= (2 \times 23.8\,\text{cm/s}) - 16.2\,\text{cm/s}$$
$$= 31.4\,\text{cm/s}$$

Therefore, $\vec{v}_f = \vec{v}_{2.0\,s} = 31.4$ cm/s.

By studying the instantaneous velocities in the previous chart, you should observe that the velocities of the object are changing at a regular rate.

7. Determine the change in velocity ($\Delta\vec{v}$), during each time interval. Construct and complete the following chart. The first two are done for you. (Remember: $\Delta\vec{v} = \vec{v}_f - \vec{v}_i$)

Time (s)	Change in Velocity (cm/s)
0.0	
1.0	16.2
2.0	15.2
3.0	
4.0	
5.0	

8. What is the average rate of change in velocity?

9. What quantity does this determine?

10. What can you conclude about this motion of a ball rolling down a slanted table?

Check your answers by turning to the Appendix, Section 2: Activity 2.

From the Analysis and Interpretation section of the previous investigation, you were able to determine that the average rate of change of velocity was about 16 cm/s every 1.0 s. This means that the object was speeding up or accelerating at an average rate of 16 cm/s every 1.0 s or 16 cm/s per 1.0 s. This is the same as 16 cm/s/s or $16\ \text{cm/s}^2$. Since the object was increasing its velocity, this is called **positive acceleration**.

positive acceleration – acceleration of an object in which the velocity is increasing in a time interval

Even though the calculations seem quite lengthy, this method of determining the acceleration of an object is quite simple. You may review this mathematical procedure to calculate the acceleration of the ball bearing by duplicating the calculations performed using the results you obtained in Activity 1. You should obtain an average acceleration of about $16\ \text{cm/s}^2$.

The two investigations in this activity have enabled you to determine that the acceleration of an object is the rate of change in velocity of an object. This can be represented in a formula.

$$\text{acceleration} = \frac{\text{change in velocity}}{\text{time interval}}$$

$$\vec{a} = \frac{\Delta \vec{v}}{\Delta t}$$

Thus, the formula is as follows:

$$\vec{a} = \frac{\vec{v}_f - \vec{v}_i}{\Delta t}$$

final velocity, initial velocity, acceleration, time interval $(t_f - t_i)$

Note: Since acceleration is in a specified direction, it is a vector quantity.

Do the following questions to see how the formula is used in problem solving.

11. An object at rest speeds up to 20.0 m/s in 4.00 s in a given direction. What is its acceleration? (This is a positive acceleration since the object is speeding up.)

12. Acceleration means a rate of change in the velocity of an object. Can velocities only increase in speed? Explain.

Do the following question to see how decreasing velocity affects the calculation of acceleration.

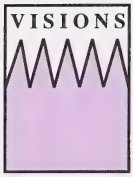
13. An object travelling at 20.0 m/s in a given direction slows down to 10.0 m/s in the same direction in 2.00 s. What is its acceleration (also called deceleration)?

Check your answers by turning to the Appendix, Section 2: Activity 2.

The answer to question 13 is a negative acceleration since the object is losing 5.0 m/s/s in a positive direction.

All of the previous examples indicated that a change in the magnitude of the velocity in a time interval determines the acceleration. Since velocity is a vector quantity and includes magnitude and direction, does an object changing direction at a regular rate, like an object travelling in a circle, also exhibit accelerated motion? Yes, but don't worry! You will confine your calculations in Science 20 to motion in one direction only.

As a final check of your understanding of acceleration, do the following questions.



14. Do questions 1 and 2 on page 397 of *Visions 2*.

15. Do question 1 on page 405 of *Visions 2*.

16. Read pages 401 and 402 of your textbook, and answer question 4 of page 405.

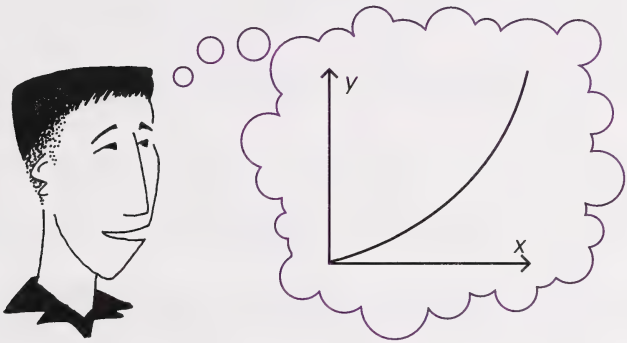
Check your answers by turning to the Appendix, Section 2: Activity 2.

In this activity, you have analysed data from an investigation using a formula-data substitution method; you were able to obtain a value of the acceleration of the object as well as justify the derivation of a formula for acceleration.

In the next activity you will analyse data on acceleration using a graphical method.

Activity 3: Graphical Analysis of Uniformly Accelerated Motion

Another method of analysing experimental data is the graphical method. This method has the added advantage of giving you a visual representation of the motion that is occurring.



In this activity, you will use graphs to analyse the sample data from Activity 2. If you obtained good results in the investigation in Activity 1 you may use these results. Compare the charts and graphs you get with the Appendix answers for this exercise.

From this graphical analysis, you will not only be able to make a qualitative comparison to the graphs obtained from uniform motion, but you should also be able to obtain the same quantitative results for acceleration as were obtained from the mathematical analysis in Activity 2.

Science Skills

- ☐ A. Initiating
- ☐ B. Collecting
- ☐ C. Organizing
- ☑ D. Analysing
- ☐ E. Synthesizing
- ☐ F. Evaluating

The following chart displays the results obtained by a student who performed an experiment of a ball rolling down a slanted table.

Time (s)	Position (cm)
0.0	0.0
1.0	8.1
2.0	31.9
3.0	72.0
4.0	128.1
5.0	199.1

1. Draw a position-time graph using the data from the previous chart. Remember that time is the independent variable; so it goes on the horizontal axis. Join the points with a smooth curve. This is the same graph as the one you made in Activity 1 of this section.

2. How does the graph of a ball rolling down a slanted table compare with the graph of an object displaying uniform motion?

3. What does the slope of the line in a position-time graph determine?

4. Join each pair of points on the position-time graph with a straight line. What is happening to the slopes of the lines that you made to join each pair of points?

5. Predict what is happening to the velocity in each interval.

6. What is the formula for determining the slope of the line of a position-time graph?

7. Calculate the slopes of the line for time intervals $t = 0.0$ s to $t = 1.0$ s, $t = 1.0$ s to $t = 2.0$ s, and so on up to $t = 5.0$ s. Construct and complete a chart of change in time (Δt) and slope.

   Note: You may use the values from the chart to calculate $\Delta \vec{d}$ since the points on the graph lie on the curve. If the points were scattered and a line of best fit had been drawn, then it would be best to choose new points which lie on the curve to determine the slope.

8. Does the slope of the line during a time interval determine an average velocity or an instantaneous velocity?

9. If the slope of the line during a time interval determines average velocity, at what exact time is the ball bearing travelling this exact velocity (instantaneous velocity)?

10. a. When is the ball bearing travelling slower than this average value of velocity?

    b. Using only a visual analysis, how can you determine that the motion is slower?

11. a. When is the ball bearing travelling faster than this average value of velocity?

    b. Using only a visual analysis, how can you determine that the motion is faster?

12. What appears to be happening to the slopes of the line of the position-time graph?

13. What does this indicate about the motion of the ball bearing displayed on the graph and what is the name of this motion?

14. Draw an average velocity-time graph using the results obtained in question 7.

    Note: The average velocities must be plotted at the midpoints of the time intervals.

15. How does the velocity-time graph for a ball bearing rolling down a slanted table compare with the graph of an object displaying uniform motion?

16. What does the slope of a velocity-time graph determine?

17. Calculate the slopes of the line for time intervals $t = 0.0$ s to $t = 1.0$ s, $t = 1.0$ s to $t = 2.0$ s, and so on up to $t = 5.0$ s. Construct and complete a chart of change in time (Δt) and acceleration $(\bar{a})$.

    Note: Use the values from the graph here, not the values from the table. Find $t = 1.0$ s on the time axis; go up to the line of the graph; then go left over to the average velocity axis; and then read the value for average velocity at $t = 1.0$ s.

18. What does the graph in question 14 indicate about the motion of the object and what is the name given to this type of motion?

19. From the review of graphing in Section 1, what does the area under the line of a velocity-time graph determine?

20. What is the area under the line of the average velocity-time graph in question 14 from $t = 0.0$ s to $t = 5.0$ s? Since the area is in the shape of a triangle, use the formula for the area of a triangle $\left(A = \frac{1}{2}ab\right)$, where a is the altitude and b is the length of the base.

21. How does your calculated value for total displacement in question 20 compare with the measured value for the position after 5.0 s from the chart preceding question 1 of this activity?

Check your answers by turning to the Appendix, Section 2: Activity 3.

To find an average value of acceleration, you can draw an acceleration-time graph. The value of the average acceleration will be the y-intercept.

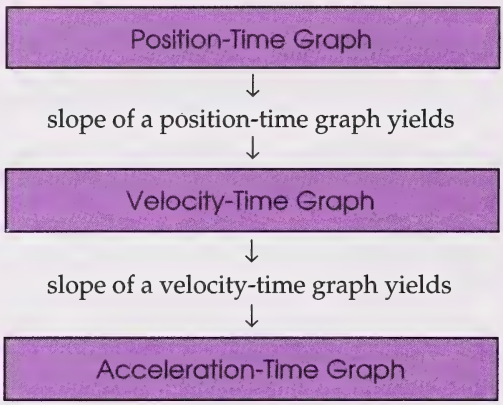
22. Draw an acceleration-time graph using the values from the chart in question 17. Plot the values for acceleration at the midpoint of each time interval.

23. Extrapolate (extend) your line to the y-axis. What is the value of the average acceleration? (This will be the y-intercept.)

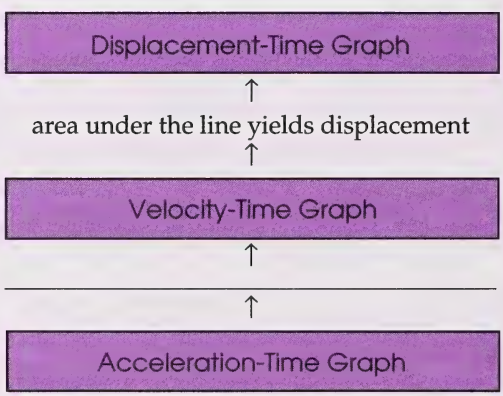
24. You have just determined a value for the average acceleration of the ball bearing using a graphical method. How does this value for the acceleration compare with the value for acceleration obtained using a formula-data substitution method from question 8 in Section 2, Activity 2?

Check your answers by turning to the Appendix, Section 2: Activity 3.

The graphical analysis you have just studied exhibits an important relationship between position, velocity, and acceleration. This can be displayed as follows:



25. Another important relationship can also be displayed as shown. Complete the relationship by filling in the blank. Notice in this relationship the term displacement is used. This is because this can be any graph; thus, the starting position is not necessarily zero.



Thus, a graphical analysis can yield the same results as a formula-data substitution method.

The graphical analysis that you just completed displayed the graphs of an object exhibiting uniform accelerated motion in a positive direction or of an object speeding up.

26. To summarize this type of acceleration, answer the following questions.

    a. What is the shape of a displacement-time graph of an object that is travelling at uniform motion?

    b. What is the shape of a displacement-time graph of an object that is accelerating or speeding up?

    c. What is the shape of a velocity-time graph of an object that is travelling at uniform motion?

    d. What is the shape of a velocity-time graph of an object that is accelerating or speeding up?

Check your answers by turning to the Appendix, Section 2: Activity 3.

Not all accelerated motion is speeding up motion; the graphs of accelerated motion can become varied and complicated, but interesting!

The following table describes a number of different motions and the type of graph which illustrates each type of motion. Displacement is used instead of position since any value can be used for the graph. Study Table 7.3 and answer question 27.

TABLE 7.3 TYPES OF ACCELERATED MOTION

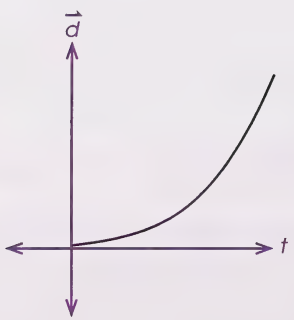
Type of Motion	Types of Graph	Shape of Graph
accelerating motion in a positive direction	displacement-time	curves upward, rising faster as displacement and time increase
	average velocity-time	straight line rising to right

decelerating motion in a positive direction	displacement-time	curves upward, rising slower as velocity and time increase
	average velocity-time	straight line dropping to right
accelerating motion in a negative direction	displacement-time	curves downward, dropping faster as displacement and time increase
	average velocity-time	straight line dropping to right
decelerating motion in a negative direction	displacement-time	curves downward, dropping slower as average velocity and time increase
	average velocity-time	straight line rising to right

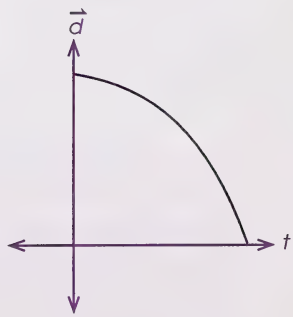
Note: The slope of a velocity-time graph is the same for motion accelerating in a positive direction and decelerating in a negative direction, as well as accelerating in a negative direction and decelerating in a positive direction.

27. Study the following sketches of graphs and describe the type of accelerated motion that is occurring. Refer back to Table 7.3 for additional help to answer this question.

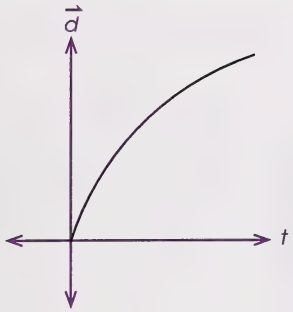
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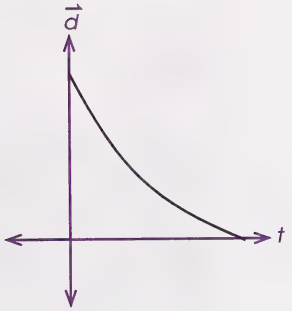
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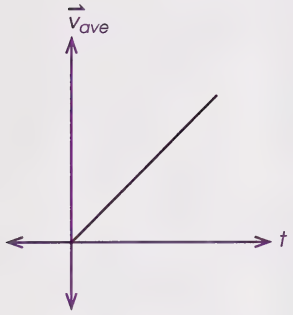
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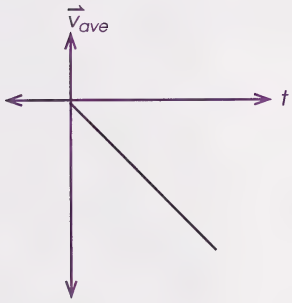
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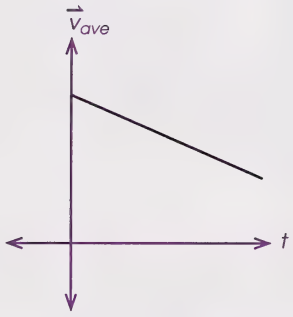
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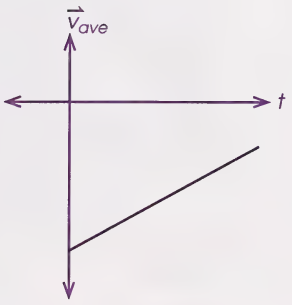
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g.



h.



Check your answers by turning to the Appendix, Section 2: Activity 3.

In this activity you have been able to analyse uniformly accelerated motion graphically, and you were able to depict various types of uniformly accelerated motion. In the next activity you will analyse a type of uniformly accelerated motion called acceleration due to gravity.

Activity 4: Uniform Acceleration due to Gravity

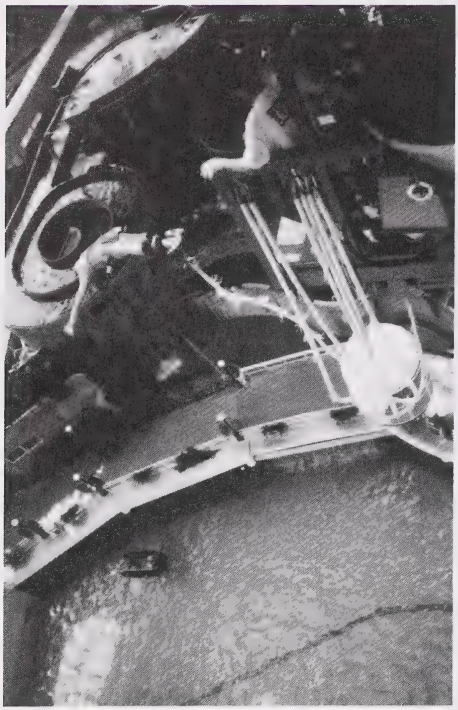


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Even though you have analysed several types of uniformly accelerated motion in Activities 2 and 3, it is very difficult to find an everyday situation where an object is undergoing a uniform acceleration.

The only typical example is an object that is falling a short distance. Since the object is falling due to the force of gravity, and since the force of gravity is nearly constant, the falling object will accelerate at a near uniform rate. A bungee jumper is an example of something in free fall.

This type of accelerated motion is called the acceleration due to gravity or the acceleration due to free fall.

In this activity you will do an investigation to determine the acceleration of free fall and to determine whether this is a uniform acceleration.

Investigation: The Acceleration of Free Fall

Follow the directions of this investigation carefully. Pay special attention to the required components, safety aspects, and applied science skills.

Purpose

Analyse the motion of an object in free fall using a graphical method, and determine a value for the acceleration of free fall.

PATHWAYS

If you have access to the laboratory equipment required for this investigation, do Part A. If you do not have access to the required equipment, do Part B.

Science Skills

- ☐ A. Initiating
- ☑ B. Collecting
- ☑ C. Organizing
- ☑ D. Analysing
- ☐ E. Synthesizing
- ☐ F. Evaluating

Part A

Materials

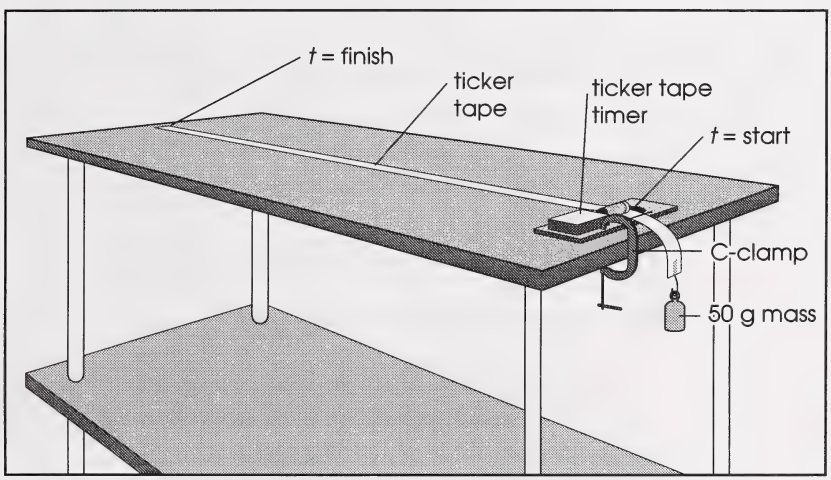
- ticker tape timer with battery (frequency of 40 Hz)
- ticker tape (at least 2 m in length)
- metre stick
- table or shelf at least 2 m above floor
- C-clamp
- 50 g mass
- stopwatch
- masking tape

Procedure

Step 1: Clamp the ticker tape timer as close to the edge of a table or shelf as possible. The table or shelf should be about 2 m above the floor.

Step 2: Use masking tape to fasten the ticker tape to the 50 g mass over the edge of a table or shelf.

Step 3: Pass the ticker tape through the ticker tape timer and lay the tape flat on the table. Make sure there are no kinks in the tape and that it is able to pass freely through the timer.



Step 4: Using your stopwatch, practise timing the fall of the 50 g mass several times until you feel confident. Drop the 50 g mass off the table and begin your stopwatch; then stop it as soon as the 50 g mass hits the floor. (Now you are ready to do the investigation.)

Step 5: First mark the beginning of the tape at the ticker as t = start, as shown in the diagram. Turn on the ticker tape timer. Drop the 50 g mass and at the same instant start the stopwatch. When the 50 g mass hits the floor, stop the watch.

Step 6: Mark the last tick on the tape with the time on the stopwatch. Remove the tape and analyse the tape as follows.

- Lay the tape on the table and count the number of ticks from the mark t = start to the last tick. Record this in Observations.
- Using ticks from near the centre of the tape, label six consecutive ticks as 0, 1, 2, 3, and so on.
- Measure the distances from 0 to 1, 0 to 2, 0 to 3, and so on.

Step 7: Make a chart like the one in the Observations section, and record your values in the chart. Make your measurements to the nearest millimetre.

Observations

1. The following will give you a method to calculate a time interval unit between ticker marks for your experiment results.

   a. total time elapsed from t = start to t = finish = _____

   b. total number of ticker marks from t = start to t = finish = _____

   c. To calculate the time interval between ticker marks, use the following:

$$\frac{\text{total number of ticker marks}}{\text{time from } t = \text{start to } t = \text{finish}} = \frac{\text{1 ticker mark}}{\text{time for 1 ticker mark}}$$

time for 1 ticker mark = _____

2. Construct and complete the following chart.

Ticker Mark	Time (s)	Position (cm)
0	0.000	
1		
2		
3		
4		
5		

Analysis and Interpretation

3. Draw a position-time graph using data from the chart. Put time (t) on the horizontal axis and position $(\vec{d})$ on the vertical axis. Choose an appropriate scale for each axis.

4. Calculate the average velocity of each interval in the previous chart and record the values in the following chart. Calculate the values to two significant digits. The first two calculations have been done for you.

Time (s)	Average Velocity (cm/s)	Average Velocity (m/s)
0.000		
	6.2×10^{1}	6.2×10^{-1}
0.026		
	8.9×10^{1}	8.9×10^{-1}
0.052		
0.078		
0.104		
0.130		

Calculate interval 0.000 s – 0.026 s.

$$\vec{v}_{ave} = \frac{\Delta \vec{d}}{\Delta t}$$
$$= \frac{1.6\text{ cm} - 0.0\text{ cm}}{0.026\text{ s} - 0.000\text{ s}}$$
$$= \frac{1.6\text{ cm}}{0.026\text{ s}}$$
$$= 62\text{ cm/s}$$
$$= 6.2 \times 10^{1}\text{ cm/s}$$
$$= 6.2 \times 10^{-1}\text{ m/s}$$

Calculate interval 0.026 s – 0.052 s.

$$\vec{v}_{ave} = \frac{\Delta \vec{d}}{\Delta t}$$
$$= \frac{3.9\text{ cm} - 1.6\text{ cm}}{0.052\text{ s} - 0.026\text{ s}}$$
$$= \frac{2.3\text{ cm}}{0.026\text{ s}}$$
$$= 89\text{ cm/s}$$
$$= 8.9 \times 10^{1}\text{ cm/s}$$
$$= 8.9 \times 10^{-1}\text{ m/s}$$

Note: $1\text{ m} = 100\text{ cm}$

5. Draw an average velocity-time graph using the data from the chart in question 4. Remember to plot the points at the midpoint of the interval; then draw a line of best fit.

6. Calculate the total slope of the average velocity-time graph.

7. What does this value represent?

8. If the acceleration due to gravity for this area is $9.81\,m/s^2$, how does this compare to the value you obtained?

Check your answers by turning to the Appendix, Section 2: Activity 4.

End of Part A

Science Skills
- ☐ A. Initiating
- ☐ B. Collecting
- ☑ C. Organizing
- ☑ D. Analysing
- ☐ E. Synthesizing
- ☐ F. Evaluating

Part B

Materials

- ticker tape data provided in the Appendix
- graph paper
- pencil and paper

Procedure

Using the same materials and following Steps 1 to 7 in the procedure of Part A of this investigation, a student performed the experiment and achieved the results as displayed on the ticker tape in the Appendix. The dots are numbered 0, 1, 2, and so on.

Step 1: Measure the distances from 0 to 1, 0 to 2, 0 to 3, and so on to the nearest millimetre.

Step 2: Make a chart similar to the one in the Observations section of Part A.

Step 3: Record your values in your chart.

Observations

The section of ticker tape, shown in the Appendix, is only part of the entire ticker tape. Use the following information to calculate a unit time interval between ticker marks.

9. If the total time elapsed from the first mark to the final mark is $= 0.64\,s$ and the total number of ticks on the tape is 25, determine the calibration of the time marks. See the calculation under Observations in Part A.

Analysis and Interpretation

10. Now go back to Part A of this investigation and complete questions 2 to 7.

Check your answers by turning to the Appendix, Section 2: Activity 4.

End of Part B

In this activity you were able to observe an object moving with uniform acceleration, and you were able to determine this value as close to $9.81\,m/s^2$ as possible. This value for the acceleration due to free fall is given the symbol a_g or g.

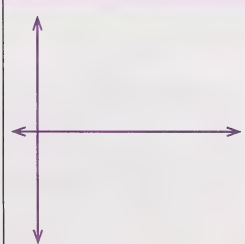
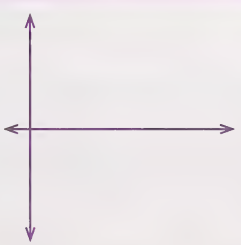
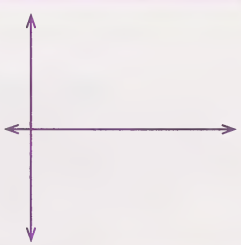
Follow-up Activities

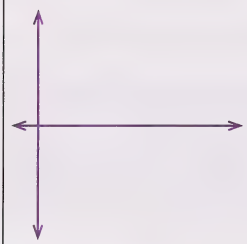
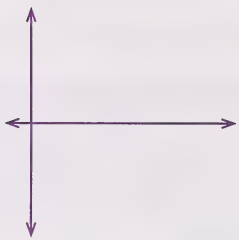
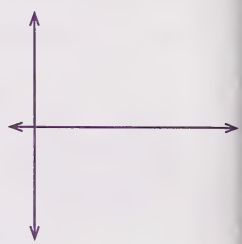
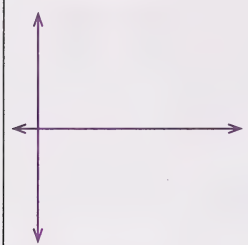
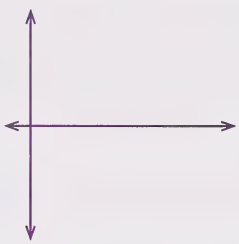
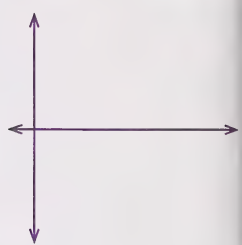
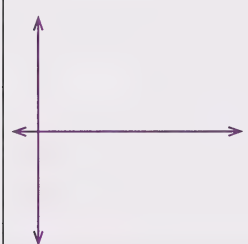
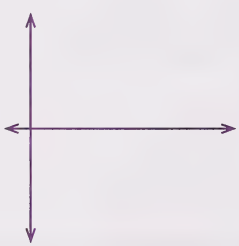
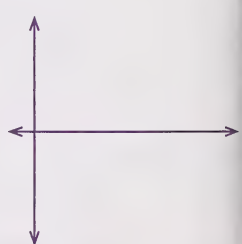
If you had difficulties understanding the concepts in the activities, it is recommended that you do the Extra Help. If you have a clear understanding of the concepts, it is recommended that you do the Enrichment.

Extra Help

Do the following questions to review important concepts from Section 2.

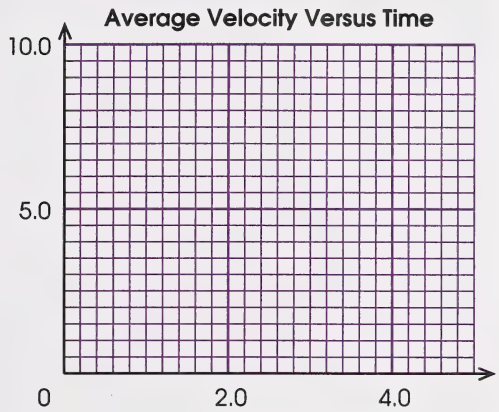
1. Complete the following chart by drawing a sketch of a graph in the axes provided to describe the motions indicated. Label the axes appropriately.

Type of Graph	TYPE OF MOTION EXHIBITED BY AN OBJECT		
	Uniform Motion	Uniformly Accelerated Motion	Uniformly Decelerated Motion
Sketch a displacement-time graph of an object travelling in a positive direction.			

Sketch a displacement-time graph of an object travelling in a negative direction.			
Sketch a velocity-time graph of an object travelling in a positive direction.			
Sketch a velocity-time graph of an object travelling in a negative direction.			

2. Use the following data chart to calculate the average acceleration of the object using the two methods you studied in Section 2.

Time (s)	Average Velocity (cm/s)
0.0	
	2.0
1.0	
	4.0
2.0	
	6.0
3.0	
	8.0
4.0	
	10.0
5.0	

METHODS TO SOLVE FOR AVERAGE ACCELERATION	
Method 1	**Method 2**
Use formula-data substitution method in the formula $\vec{a} = \frac{\vec{v}_f - \vec{v}_i}{\Delta t}$.	Use graphical method by finding the total slope of the graph. Make and complete a graph like the following. Label the axes. 

3. Complete the following chart by answering the question in the first column.

Question	Type of Graph		
	Displacement-Time	Velocity-Time	Acceleration-Time
What does the slope of each graph determine?			
What does the area under each graph determine?			

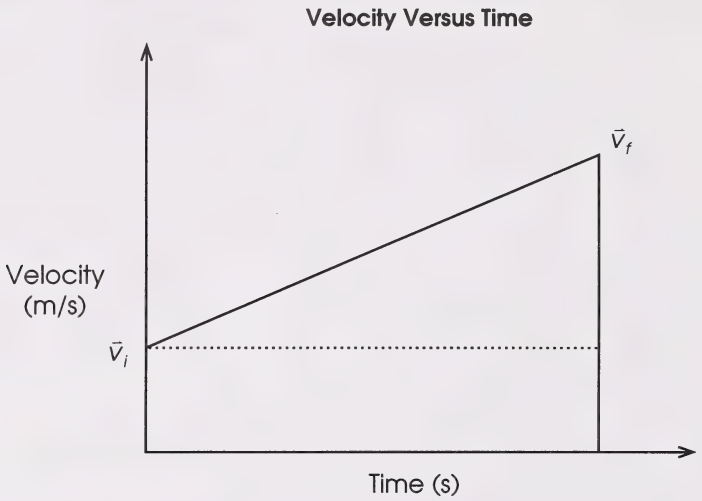
Check your answers by turning to the Appendix, Section 2: Extra Help.

Enrichment

You should now be able to use the concepts from Section 2 to answer the following questions.

Do one of the following questions. Show all your work.

1. Study the following graph of an accelerating object.



You have studied that the area under the line of a velocity-time graph determines the total displacement of an object. Thus, the formula for determining the total displacement of an accelerating object is as follows:

$$\vec{d} = \vec{v}_i t + \frac{1}{2}\vec{a}t^2$$

Use the information from the previous graph to derive this equation. Note: Although this is a displacement $\left(\Delta\vec{d}\right)$, the delta notation (Δ) has been omitted for convenience of writing the formula.

2. A Boeing 747 aircraft with a mass of 3.32×10^5 kg is set to take off from Edmonton International Airport. The pilot accelerates the plane and roars down the runway. After travelling 800 m down the runway, the Boeing 747 achieves a speed of 54.2 m/s and lifts off. Use the knowledge from this section and the previous data to calculate the acceleration down the runway.



Check your answers by turning to the Appendix, Section 2: Enrichment.

Conclusion

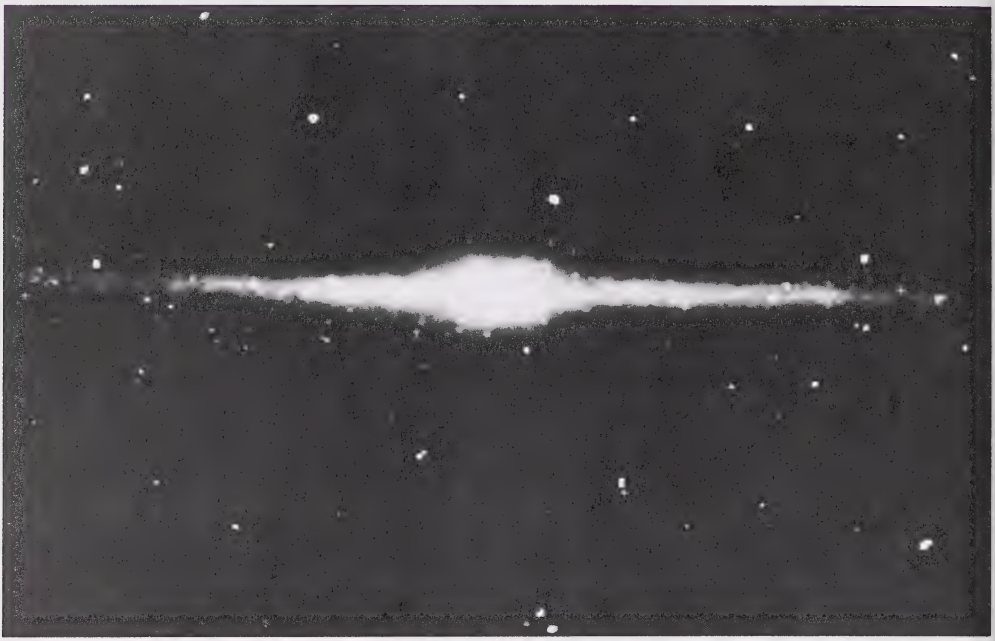
You have now completed Section 2. Through investigations, you have determined that another factor that distinguishes one motion from another is change in the motion. This change can be a change in magnitude or a change in direction, and the type of motion exhibiting this change is accelerated motion. In the next section, you will investigate what causes an object to travel at uniform motion or at accelerated motion.

ASSIGNMENT

Turn to your Assignment Booklet and do the assignment for Section 2.

Section

3 Newton's Laws of Motion



NASA

Have you ever really watched the motion of the sun, moon, and stars as they travel across the night sky? Do they all travel with the same type of motion? The sun rises in the east and sets in the west with such a definite precision that you can set your clocks to this motion. Yet, is this a uniform motion or is it an accelerated motion? Do the moon and the stars rise and set with the same predictable motion? More importantly, do all heavenly bodies move around the Earth or is there some other system to describe their motions?

Finally, what is the cause of these motions and why do they continue this exact motion day after day? These and other questions have puzzled scientists since the beginning of time. They realized that understanding the causes of motions in the heavens could lead to understanding the causes of all motions of objects on Earth.

In the previous sections you studied two of the most common types of motion – uniform motion and uniform accelerated motion. In this section you will study the causes of these and all motions, and you will see how the causes of these motions developed into the most important scientific laws in classical physics – Newton's three laws of motion.

Activity 1: Newton's First Law of Motion

Up until the 1500s, the motion of all objects and the cause of all motions were explained using ancient Greek theories proposed by Aristotle (384 B.C. – 322 B.C.) and Ptolemy (A.D. 127 – A.D. 145).

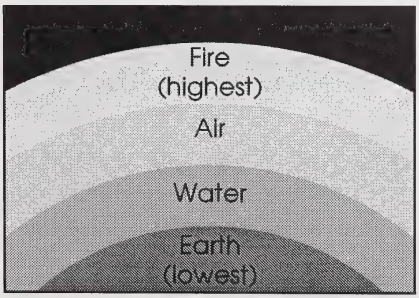
These theories were so logical that they lasted for over 2000 years.

In this activity you will be introduced to these ancient theories. You will see how it took the genius of Galileo (1564 – 1642) to contradict these theories and the mathematical brilliance of Newton (1642 – 1727) to introduce a new theory, published as Newton's First Law of Motion.

The Greek theory of motion was simple and logical.

First, there are only two types of motion on Earth. These motions are explained in Table 7.4.

TABLE 7.4 TWO TYPES OF MOTION ON EARTH (GREEK THEORY)

Natural Motion	Violent Motion
Natural motion occurs when an object moves naturally at uniform motion to its most dominant element. For example, a rock in air moves downwards to Earth because it is composed mainly of Earth. According to Aristotle, there were only four types of elements on Earth: earth, water, air, and fire. Each element was ranked vertically according to position.  	According to Aristotle, **violent motion** occurs whenever a force (a push or a pull) is applied to an object. When the force is removed, the object stops moving. A wagon on Earth will stay at rest if no force is applied. If you push the wagon, it moves. If you remove your force, it stops.

atural motion – otion of an bject towards its atural place or ement

olent motion – otion of an bject which ust be ustained by a rce

1. Use Greek theory to answer the following questions.

   a. Why does the flame of a fire reach into the sky? What type of motion is this?

   b. Why does an apple in a tree fall to the ground? What type of motion is this?

   c. When you let a ball bounce on the ground, why does it eventually stop? What type of motion is this?

Check your answers by turning to the Appendix, Section 3: Activity 1.

Secondly, there was only one type of motion in the heavens. The sun, the moon, the stars, and all the planets followed a different set of laws and a different motion. According to Ptolemy and Aristotle, the Earth was the centre of the universe and all heavenly bodies moved around the Earth with uniform motion in perfect circles. This is called a **geocentric system**.

geocentric system – an Earth-centred universe with all heavenly bodies orbitting around the Earth

These theories were able to answer all questions regarding the motions of any objects up to the 1500s. At this time a Polish astronomer named Copernicus observed that the motion of the sun and planets did not fit the Aristotlean theory of perfect circles. He cautiously suggested a solar system with the sun at the centre and the planets orbitting around the sun (a **heliocentric system**).

heliocentric system – a sun-centred universe with the planets orbitting around the sun

2. During this period of time in history (1500s), it was very difficult to propose new ideas. Do you know why?

Galileo became intrigued with this new theory and the idea that if the Earth orbits the sun, it must be travelling at a tremendous speed through space.

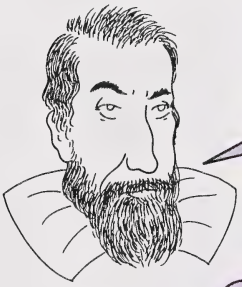
3. Do you know how fast the Earth is travelling through space? How would you calculate this?

Galileo began a study of motion. He concentrated his studies on how an object moves (kinematics).

4. Based on your previous studies, do you think the Earth is travelling with uniform or accelerated motion?

Check your answers by turning to the Appendix, Section 3: Activity 1.

Galileo began his studies by contradicting the old Aristotelian theory of motion using a hypothetical experiment. Imagine the following discussion between Galileo and Aristotle.

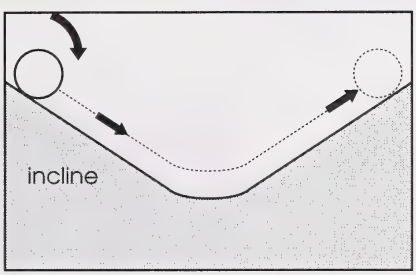


O.K. Mr. Aristotle, let me see if I got this right! An object can only move horizontally if a push or a pull acts on it.



Yes! Mr. Galileo, this type of motion is called violent motion! If the force is removed, the object must stop.





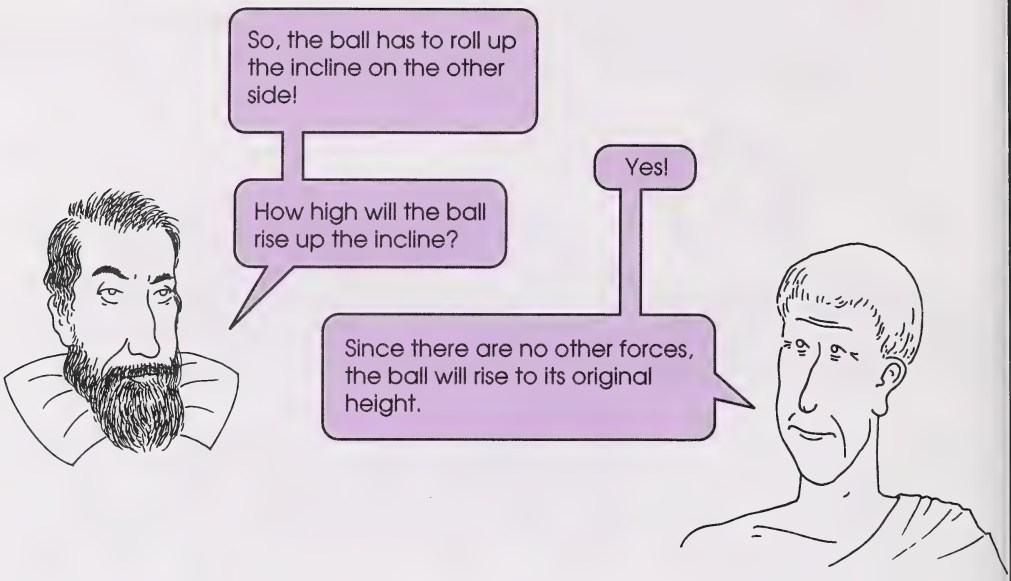


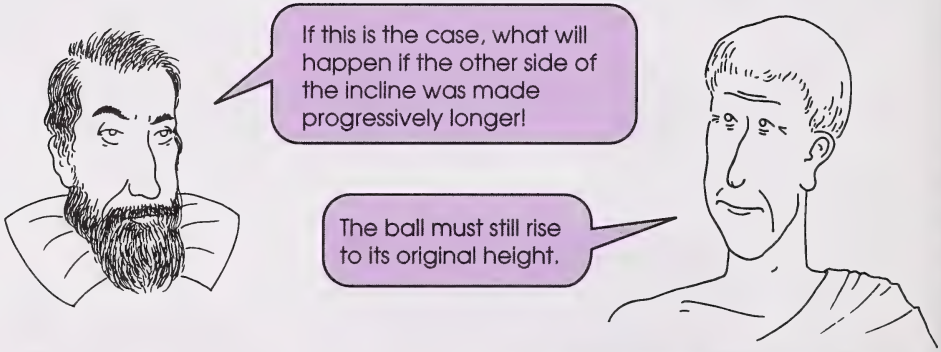
Well! Suppose a ball is rolling down a perfectly smooth incline with no outside forces like friction present. Why does the ball roll down the incline?

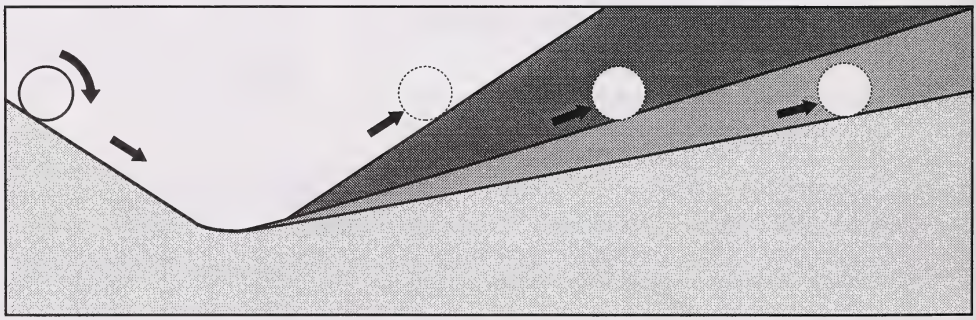
Oh! This is natural motion. The ball wants to get nearer to its natural place, which is Earth.

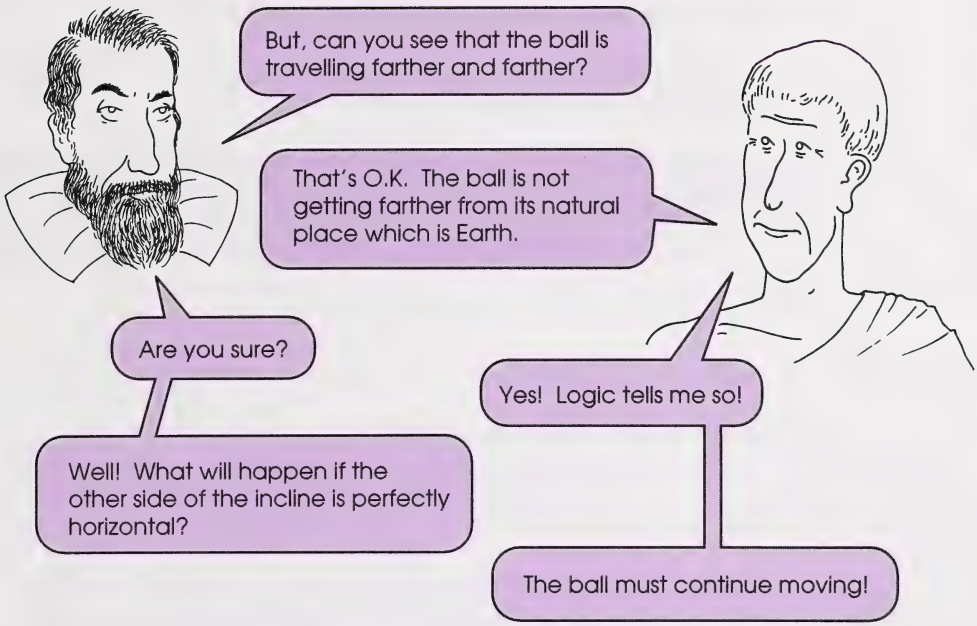
But, when the ball reaches the bottom, will it stop there?

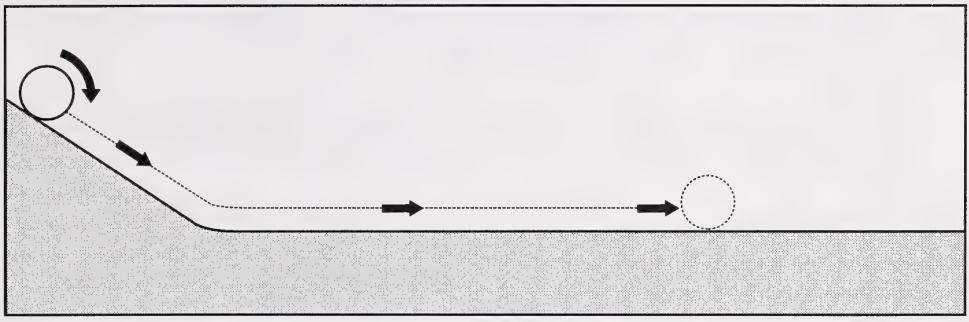
No! This is getting complicated. As the ball is rolling down, it is pushing air particles aside, creating a temporary vacuum behind it. Since nature hates a vacuum, air particles rush in behind the ball, creating a force on the ball which pushes it forward.

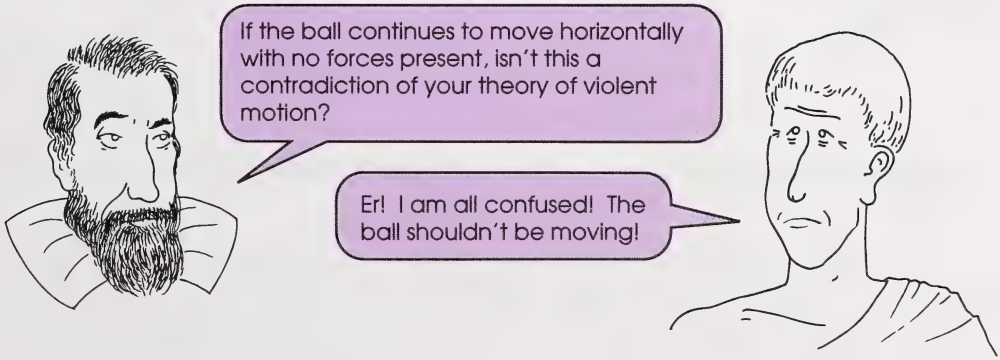

So, the ball has to roll up the incline on the other side!
How high will the ball rise up the incline?
Yes!
Since there are no other forces, the ball will rise to its original height.


If this is the case, what will happen if the other side of the incline was made progressively longer!
The ball must still rise to its original height.




But, can you see that the ball is travelling farther and farther?
That's O.K. The ball is not getting farther from its natural place which is Earth.
Are you sure?
Yes! Logic tells me so!
Well! What will happen if the other side of the incline is perfectly horizontal?
The ball must continue moving!




If the ball continues to move horizontally with no forces present, isn't this a contradiction of your theory of violent motion?
Er! I am all confused! The ball shouldn't be moving!

5. What is the contradiction?

6. How would Galileo conclude this hypothetical experiment concerning the motion of the ball on the horizontal incline?

Check your answers by turning to the Appendix, Section 3: Activity 1.

This began the downfall of Aristotlean mechanics.

force – a push or a pull exerted on an object

It should be noted that Galileo was a very popular teacher, and his influence began to scare the nobility and the church leaders. As a consequence, he was put on trial and, subsequently, was forbidden to teach his new theories.

dynamics – a study of why objects move

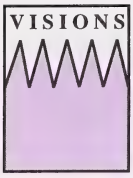
The year of Galileo's death (1642) was also the year of the birth of another powerful scientist named Newton.



Read the Biography of Isaac Newton on page 413 of *Visions 2*.

Newton became intrigued with motion and its causes, and he realized that the fundamental difference between uniform motion and accelerated motion was the concept of **force**. He began a study of the causes of motion called **dynamics**, which he published in a book called *Principia*.

Using Galileo's theory, Newton first tried to explain the motion of an object with uniform motion.



Read page 416 of *Visions 2;* then answer the following questions.

7. If an object is at rest, is this a uniform motion?

8. What does Newton's First Law state about an object at rest?

9. Read the two paragraphs in the middle of page 414 of *Visions 2*. Can you use your answer to question 8 to explain why your books that you left on the table at night are still there in the morning?

10. What does Newton's First Law state about an object that is travelling horizontally with a uniform motion?

11. Use this statement to explain why the ball in Galileo's hypothetical experiment will continue to travel in a straight line horizontally.

12. State both parts of Newton's First Law in your own words.

13. Use Newton's First Law to explain what happens in each of the following situations.

    a. A car is at rest at an intersection. Suddenly, it accelerates forward. What happens to the passengers in the car?

    b. A car is travelling on a highway at uniform motion. Suddenly, it stops. What happens to the passengers in the car?

    c. A car is travelling on a highway at uniform motion. Suddenly, it turns a corner. What happens to the passengers in the car?

    d. In each of the previous examples, what is the importance of seat belts?

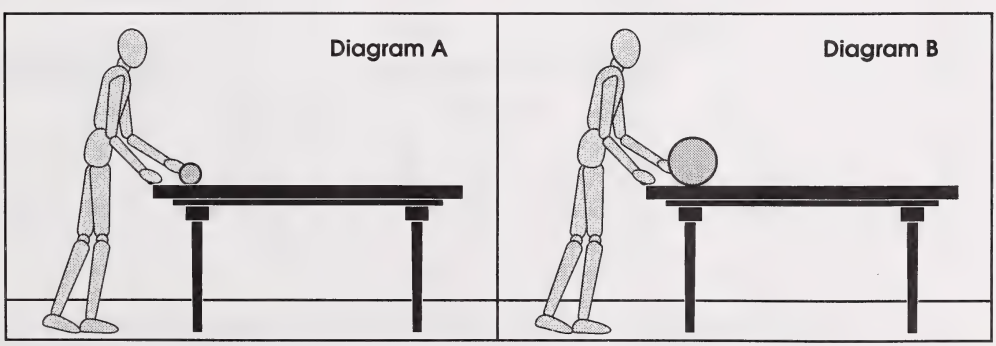
Check your answers by turning to the Appendix, Section 3: Activity 1.

Newton's First Law of Motion

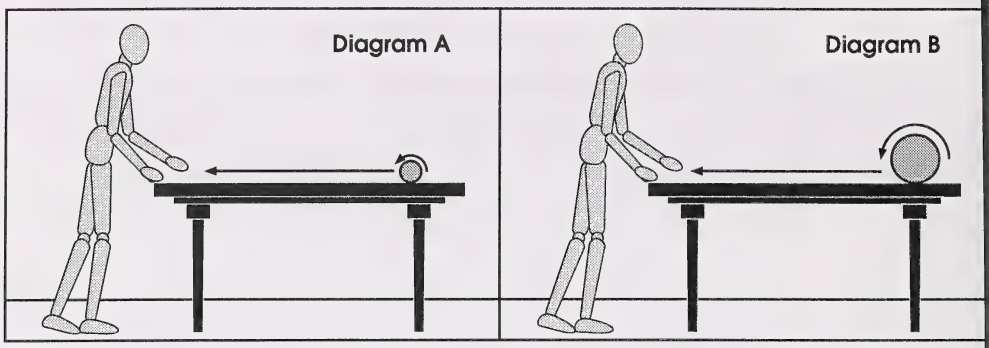
An object at rest will remain at rest, and an object in uniform motion will remain in uniform motion unless acted upon by an unbalanced force.

Newton realized that all objects at rest will remain at rest and that all objects in uniform motion will remain in uniform motion in a straight line unless an unbalanced force is present. He then realized that some objects want to maintain this uniform motion more than others.

14. If both objects in the following diagram are made of the same substance and are at rest at the start, which object is easier to set in motion?



15. If both objects in the following diagrams are made of the same substance and are travelling at uniform motion, which object is easier to stop?



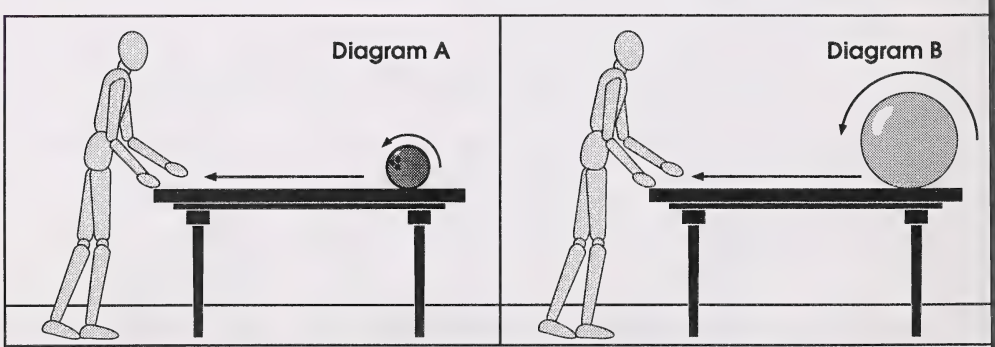
Check your answers by turning to the Appendix, Section 3: Activity 1.

In the previous diagrams, the object in Diagram B wants to stay at rest or in uniform motion more than the object in Diagram A. The property of an object to maintain a state of rest or a state of uniform motion is called **inertia**.

inertia – the property of an object to maintain a state of rest or a state of uniform motion

16. Which object seems to have more inertia?

17. Why does the object in Diagram B seem to have more inertia than the object in Diagram A? Consider the following diagram and answer the following questions.



a. Which object is easier to stop?

b. Does size or **volume** determine the object's ability to maintain a uniform motion?

volume – the space that an object occupies

c. Why does the bowling ball have more inertia than the balloon?

Check your answers by turning to the Appendix, Section 3: Activity 1.

If you have access to the video entitled *Inertia* from the *Mechanical Universe* series, ACCESS Network, you may wish to view this video for a greater understanding of inertia. This video may be obtained through your local library or school.

The ability of an object to maintain a state of rest or a state of uniform motion is called inertia, and the inertia of an object is determined by the mass of the object.

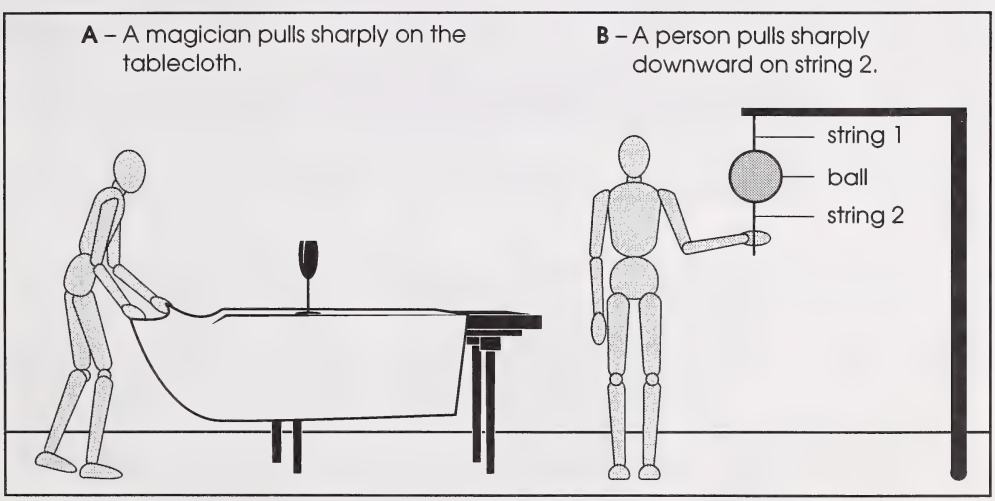
18. In previous science courses, the mass of an object was defined as the amount of matter in an object. What could be another definition for the mass of an object?

19. In what unit is mass usually measured?

VISIONS

20. Read the paragraph in the middle of page 420 of *Visions 2*. What is another name for Newton's First Law?

21. Newton's First Law can be used to explain many physical phenomena. Study the following diagrams, and use the first law of motion to explain what will happen and why.

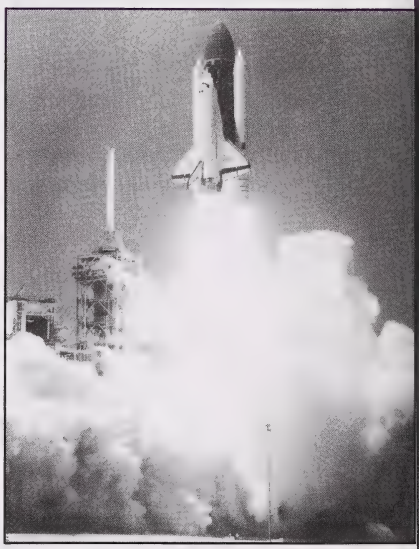


Check your answers by turning to the Appendix, Section 3: Activity 1.

In this activity you learned that in the absence of unbalanced forces, an object will maintain a state of rest or a state of uniform motion in a straight line. In the next activity you will investigate what happens to the motion of an object when an unbalanced force is applied to an object.

Activity 2: Newton's Second Law of Motion

Have you ever watched a jet, or a race car, or a rocket just before takeoff? All of these vehicles were initially at rest, obeying Newton's First Law, until the command for takeoff was given. Suddenly, the vehicles surged forward, changing their velocities at an astounding rate.



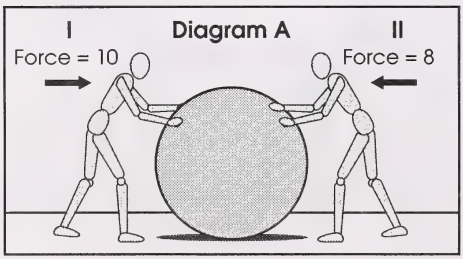
NASA

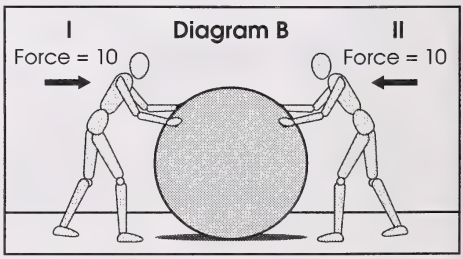
Have you ever wondered what the exact cause of these accelerations is?

Why does one vehicle seem to accelerate more than the others?

Three hundred years ago, as Newton was watching his famous apple fall from a tree, he realized that a uniform motion can only be maintained if no unbalanced forces act on an object (Newton's First Law of Motion). This does not mean that no forces are acting on the object in uniform motion, rather that all the forces acting on the object are balanced.

1. To explain the difference between balanced and unbalanced forces, study the diagrams and answer the questions that follow.





a. What is the resultant force acting on the object in Diagram B?

b. Will the object in Diagram B maintain its state of rest?

c. Does the object in Diagram B obey Newton's First Law of Motion, even though there are forces acting on it? Why?

d. Why are the forces in Diagram B called balanced forces?

e. What is the resultant force acting on the object in Diagram A?

f. Will the object in Diagram A maintain its state of rest?

g. Will the object in Diagram A obey Newton's First Law of Motion? Why?

h. Why are the forces in Diagram A called unbalanced forces?

2. It appears that if an unbalanced force acts on an object, the motion of the object must change. What type of motion results from a change in motion?

Check your answers by turning to the Appendix, Section 3: Activity 2.

The cause of accelerated motion must be an unbalanced force. The following is a summary of Newton's first and second laws of motion.

Newton's First Law	Newton's Second Law
If **balanced** forces act on an object, the object maintains a **uniform motion**.	If **unbalanced** forces act on an object, the object undergoes a change in motion or **acceleration**.

Why does one object accelerate more than another? To answer this question, do the following investigation.

Science Skills
- A. Initiating
- B. Collecting
- C. Organizing
- D. Analysing
- E. Synthesizing
- F. Evaluating

Investigation: Factors Affecting Acceleration of an Object

Follow the directions of this investigation carefully. Pay special attention to the required components, safety aspects, and applied science skills.

Purpose

Investigate the factors that will determine the acceleration of an object.

Background Information

3. Complete the following sentences to formulate a hypothesis for this investigation.

   If an unbalanced force causes an object to accelerate, the two factors that must determine how much it will accelerate are _____ and _____. Also, the amount of acceleration will increase as the _____ increases, and the amount of acceleration will decrease as the _____ increases.

Materials

- ticker tape timer (set at $\frac{1}{10}$ s)
- ticker tape
- triple beam balance or scale
- three masses (50 g, 100 g, and 150 g)
- various additional masses (200 g, 500 g)
- rolling dynamics cart
- long table
- string
- pulley
- tape

PATHWAYS

If you have access to laboratory facilities, do this investigation. If not, the data has been collected for you in the form of ticker tapes found at the end of the Appendix.

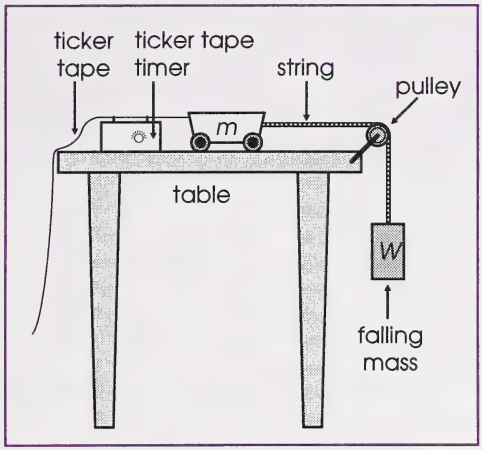
Read through the procedure for each part so you know how the experiment is done and what the difference is between the two parts.

Part A

You will investigate the effect of an unbalanced force on the acceleration of a cart.

Procedure

Step 1: Assemble the apparatus as shown in the following diagram. Be sure the ticker tape pulls evenly through the ticker tape timer.



Step 2: Set the ticker tape timer for $\frac{1}{10}$ s intervals.

Step 3: Attach a 50 g mass to the end of the string as the falling mass. (Hold the mass until you are ready.)

Step 4: Turn on the ticker tape timer and release the falling mass.

Step 5: Remove the ticker tape.

Step 6: Number the dots from 0 to 5 if there are six dots. There may be only five dots with the heavier masses.

Step 7: Make a chart like the one in the Observations section for each of the 50g, 100 g, and 150 g falling masses.

Step 8: Measure the distances from 0 to 1, 1 to 2, 2 to 3, and so on, and record these values in the chart for the 50.0 g falling mass. Measure to the nearest tenth of a centimetre (nearest millimetre).

Step 9: Repeat the investigation for 100 g and 150 g falling masses and record your values in the appropriate column in charts for these masses.

Observations

4. Complete the chart for each falling mass. Use the sample ticker tapes at the end of the Appendix and the calculations in the following chart only if you are unable to do the investigation. Otherwise, use your measurements for the calculations. Make your measurements to the nearest tenth of a centimetre (nearest millimetre).

   Calculate the average velocity during each time interval using the formula $\vec{v}_{ave} = \frac{\Delta \vec{d}}{\Delta t}$.

   The first three calculations for the 50 g mass are done for you.

50 g Falling Mass		
Time	**Displacement from Previous Dot**	**Average Velocity During Each Time Interval**
0.00 s		
	0.7 cm	$\vec{V}_{ave} = \frac{\Delta \vec{d}}{\Delta t} = \frac{0.7\text{ cm}}{0.10\text{ s}} = 7\text{ cm/s}$
0.10 s		
	1.8 cm	$\vec{V}_{ave} = \frac{\Delta \vec{d}}{\Delta t} = \frac{1.8\text{ cm}}{0.10\text{ s}} = 18\text{ cm/s}$
0.20 s		
	3.1 cm	$\vec{V}_{ave} = \frac{\Delta \vec{d}}{\Delta t} = \frac{3.1\text{ cm}}{0.10\text{ s}} = 31\text{ cm/s}$
0.30 s		
0.40 s		
0.50 s		

Analysis and Interpretation

5. a. Draw a graph of average velocity versus time for 50 g, 100 g, and 150 g falling masses. Pick the line of best fit through the points for each set of points. Draw these three graphs on the same set of axes. (Plot time on the horizontal axis).

   b. Calculate the slope of each line from the graph. Use total rise over total run to find the slope of each line.

6. What does the slope of an average velocity versus time graph determine?

7. What is one of the factors that affects the acceleration of an object?

8. Based on your graphs, how is the acceleration affected by this factor?

9. Write a mathematical expression displaying this relationship.

Check your answers by turning to the Appendix, Section 3: Activity 2.

End of Part A

Part B

You will investigate the effect of the mass of a cart on the acceleration of that cart.

Procedure

Step 1: Repeat Steps 1 to 6 of the Procedure section in Part A using only the 50 g falling mass.

Note: The results of the first run in Part A are the same as the results for the first run in Part B.

Step 2: Use a balance to measure the mass of the cart to the nearest gram.

Step 3: Double the accelerating mass for the second run.

Note: The total accelerating mass is equal to the mass of the cart plus the 50 g mass.

Step 4: Triple the accelerating mass for the third run.

Step 5: Make a chart like the one in the Observations section in Part A for each accelerating mass.

Observations

10. Complete the chart for each accelerating mass. Use the sample ticker tapes at the end of the Appendix if you are unable to do the investigation. Measure the distances from 0 to 1, 1 to 2, 2 to 3, and so on for each run. Record these measurements in your charts. Make your measurements to the nearest tenth of a centimetre (nearest millimetre). The first three calculations for the 400 g accelerating mass are done for you.

Original Mass of Cart = 350 g + 50 g = 400 g		
Time	**Displacement From Previous Dot**	**Average Velocity of Cart During Each Time Interval**
0.00 s		
0.10 s	0.7 cm	$\vec{v}_{ave} = \frac{\Delta \vec{d}}{\Delta t} = \frac{0.7\text{ cm}}{0.10\text{ s}} = 7\text{ cm/s}$
0.20 s	1.8 cm	$\vec{v}_{ave} = \frac{\Delta \vec{d}}{\Delta t} = \frac{1.8\text{ cm}}{0.10\text{ s}} = 18\text{ cm/s}$
0.30 s	3.1 cm	$\vec{v}_{ave} = \frac{\Delta \vec{d}}{\Delta t} = \frac{3.1\text{ cm}}{0.10\text{ s}} = 31\text{ cm/s}$
0.40 s		
0.50 s		

Analysis and Interpretation

11. Draw a graph of average velocity versus time for the three situations on the same set of axes. (Plot time on the horizontal axis.)

12. Calculate the slope of each line from the graph. Use total rise over total run for each line.

13. What does the slope of this graph determine?

14. Based on this part of the investigation, what is another factor that affects the acceleration of an object?

15. How is the acceleration affected by this factor?

16. Write a mathematical expression displaying the relationship.

Check your answers by turning to the Appendix, Section 3: Activity 2.

End of Part B

In the investigation you determined that the acceleration of an object depends on the mass involved and the unbalanced force applied. This initiated the formation of Newton's Second Law.

Newton's Second Law

If an unbalanced force acts on a mass, the mass will accelerate in the direction of the force such that the acceleration varies directly with the force and indirectly with the mass.

Mathematically this can be expressed as shown.

- $\vec{a} \propto \vec{F}$ ($\vec{a}$ varies directly with the $\vec{F}$; or as $\vec{F}$ increases, $\vec{a}$ increases.)
- $a \propto \frac{1}{m}$ (a varies indirectly with the m; or as m increases, a decreases.)

Combining the two relationships will yield $\vec{a} \propto \frac{\vec{F}}{m}$.

If the proper units are used, you can rearrange the relationship to the equation that follows:

mass of the object (kg)

$$\vec{F} = m \times \vec{a}$$

unbalanced force acting on the object ($kg \bullet m/s^2$)

acceleration of the object (m/s^2)

This is Newton's Second Law of Motion in mathematical form. Notice that the vector symbol is used. This indicates that direction is important. Sometimes you will see the formula written as $F = ma$. In this form only magnitude or size of the force is important.

17. What is the unit for force?

Check your answers by turning to the Appendix, Section 3: Activity 2.

Since the unit for force seemed so awkward, a force unit of $1\ kg \bullet m/s^2$ was called 1 newton (N) of force. You now have a derived unit for force.

DID YOU KNOW?

A medium-sized apple held in your hand will exert a downward force of about 1 N.

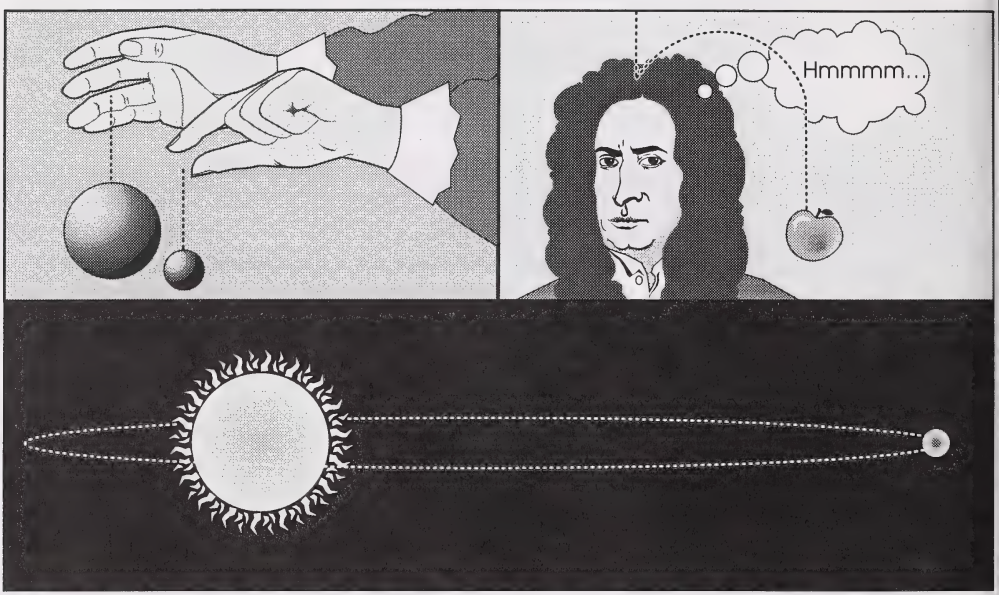
Newton's Second Law of Motion is extremely important in describing the motion of an object when an unbalanced force is acting on it. In the next activity you will study how to apply this law of motion to various situations.

Activity 3: Applications of Newton's Second Law of Motion

You may recall hearing about Galileo's famous experiment in which he dropped different size objects from the leaning tower of Pisa. After Galileo had performed his famous experiment, confirming his hypothesis that an object falling to the Earth does indeed accelerate, the question of **why** objects fall to the Earth in the first place still had to be answered.

Later, as Newton was developing his Second Law of Motion, he concluded that if an object with mass is exhibiting accelerated motion, there must be an unbalanced force acting on the object ($F = m \times a$). Note: Vector symbols are not used here because direction is not indicated. But, what is the nature of the force that is pulling an object to the Earth. Also, if the Earth is to orbit the sun in circular orbit, a form of accelerated motion, are these forces similar?

As he sat under the apple tree pondering these questions, he observed the simple phenomenon of an apple falling from the tree. Suddenly, a thought was born! Could his Second Law of Motion be applied not only to explain the motion of a falling apple, but also to explain the action of the Earth and other planets around the sun?



If Newton could determine the nature of the force causing the apple to fall to the ground, the applications of his Second Law of Motion would be astounding!

As you proceed through this activity, you will discover how Newton's Second Law of Motion became one of the most essential and fundamental laws in all of science. The key that initially opened the door to the Second Law of Motion eventually opened the doors to an understanding of many other laws and phenomena in science.

The key began with a simple progression of calculations.

First, begin with a few simple calculations involving Newton's Second Law.

1. An object with a mass of 5.00 kg is pushed horizontally by a force of 10.0 N, causing it to accelerate. Find the acceleration of the object. (Use the formula $\bar{F} = m\bar{a}$ and solve for $\bar{a}$. The vector symbol is used since the object is moving in a particular direction. In this case, it is moving horizontally.)

This confirms the second law of motion. An unbalanced force will cause a mass to accelerate. What happens if two forces act on an object as in the next question?

2. An object with a mass of 5.00 kg is pushed horizontally by two forces of 10.0 N each in the same direction. Calculate the acceleration of the object.

3. An object with a mass of 5.00 kg is pushed by two forces of 10.0 N each in opposite directions. Since the forces are opposite in direction one must be positive and the other must be negative. Calculate the acceleration of the object.

Check your answers by turning to the Appendix, Section 3: Activity 3.

This last example not only confirms Newton's Second Law but also confirms Newton's First Law. Unless an unbalanced force acts on an object, the object will maintain a state of rest or uniform motion. Things seemed to be working out quite well for Newton until he observed the following phenomenon.

A perfectly round mass of 1.00 kg, rolling with a uniform velocity of 2.00 m/s on a level surface, should continue to move at 2.00 m/s endlessly, according to the First Law of Motion.



But, as observed, everything in motion eventually slows down and stops. Was this a contradiction? Newton realized that another force must be present. What was this force?

VISIONS

Read pages 416 to 419 of *Visions 2;* then answer the following questions.

4. What is the force that eventually causes moving objects to stop?

5. Upon what factors does the force of friction depend?

6. What is the direction of the force of friction?

7. Describe two situations where the force of friction hinders motion.

8. Describe two situations where the force of friction aids motion.

9. A force of 10.0 N is pushing on a 5.00 kg mass. But a force of friction of 2.0 N is opposing this motion. Calculate the acceleration of the object.

Check your answers by turning to the Appendix, Section 3: Activity 3.

All of the previous examples could explain **horizontal motion** quite well. That is, unbalanced forces will cause an object to accelerate; balanced forces will cause an object to maintain a state of rest or uniform velocity. In these situations the forces acting on an object are easily explained. But, what will happen in a vertical motion (an object falling to the ground)? The object is accelerating, but what is the nature of the force that is causing the accelerated motion of an object towards the Earth? This was Newton's next task.

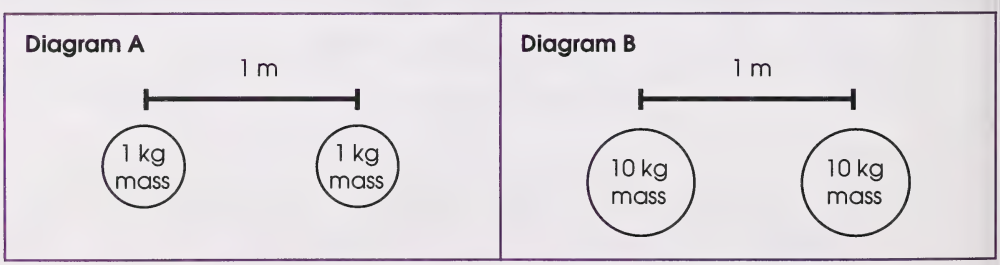
VISIONS

Read pages 421 to 423 of *Visions 2;* then answer questions 10 to 19.

10. What is the name of the attracting force that pulls the apple to the Earth, as suggested by Newton?

11. Upon what two factors does this attracting force depend?

12. Study the following diagrams, and answer the questions that follow.

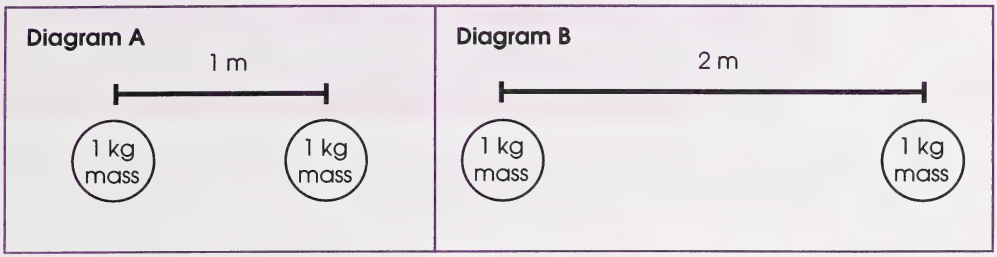


a. Will there be an attracting force between the masses in Diagrams A and B?

b. In which diagram do you think the attracting force will be greater? Why?

c. State in words the mathematical relationship between the attracting force due to gravity and the masses of the two objects involved.

13. Study the following diagrams, and answer the questions that follow.



a. In which diagram do you think the attracting force due to gravity will be greater? Why?

b. State in words the mathematical relationship between the attracting force due to gravity and the distance between the centres of the two masses.

VISIONS

14. Newton combined these two mathematical relationships into a law. State Newton's Law of Gravity as shown in the diagram on page 422 of your textbook.

15. Write Newton's Law of Gravity in mathematical form.

16. What do the following symbols represent?

a. $\vec{F}_g$ c. m_1 e. r

b. G d. m_2 f. F_g

17. Use the formula of Newton's Law of Gravity to calculate the force of gravitational attraction between the apple and the Earth. The mass of the apple is 0.100 kg; the mass of the Earth is 5.97×10^{24} kg; and the distance between the centre of the apple and the centre of the Earth is 6.40×10^{6} m $\left(G = 6.67 \times 10^{-11} \text{N} \bullet \text{m}^2 / \text{kg}^2\right)$.

Note: $\text{N} \bullet \text{m}^2 / \text{kg}^2$ is read as newton metre squared per kilogram squared.

18. If there is a force due to gravity pulling the apple to the Earth, will the apple accelerate to the Earth's surface? Why?

19. Use Newton's Second Law $(F = m \times a)$ to calculate the acceleration.

20. What did Newton call this special type of acceleration of falling objects?

21. What is the symbol given to the acceleration of falling objects?

Check your answers by turning to the Appendix, Section 3: Activity 3.

Thus, Newton's Second Law could be used to find the value of the acceleration due to gravity (g) using the following formula.

$$g = \frac{F_g}{m}$$

F_g ← force of gravitational attraction on a mass (N)

g ↑ acceleration due to gravity $\left(\text{N/kg or m/s}^2\right)$

m ↑ mass of object that is falling (kg)

The value of g could also be calculated from another equation, which can be derived from Newton's Second Law of motion and Newton's Law of Gravity. Study the following and complete the derivation:

From Newton's Second Law ($F = m \times a$), the equation for a falling mass (m_1) may be written as follows:

Equation 1: $F_g = m_1 \times g$

From Newton's Law of Gravity, the force of gravitational attraction (F_g) between the falling mass (m_1) and the Earth (m_E) is as follows:

Equation 2: $F_g = \dfrac{Gm_1m_E}{\Delta r^2}$

22. Solve for g by combining Equations 1 and 2.

23. Use the equation in the previous question to find the value of g on the surface of the Earth if $m_E = 5.97 \times 10^{24}$ kg and the distance from the centre of the Earth to the surface is 6.40×10^6 m.

24. Will the value of g be the same anywhere? If not, upon what factors does the value of g depend? $\left(\text{Hint: } g = \dfrac{Gm_E}{r^2}\right)$

25. a. If all objects experience a force of gravitational attraction (F_g), this must be a property of all objects. What is another name for the force of gravitational attraction on an object?

    b. What is another symbol for F_g?

eight – the rce of ravitational traction on an bject

    c. If you could travel to other planets in the solar system, would your **weight** be the same or different on the other planets?

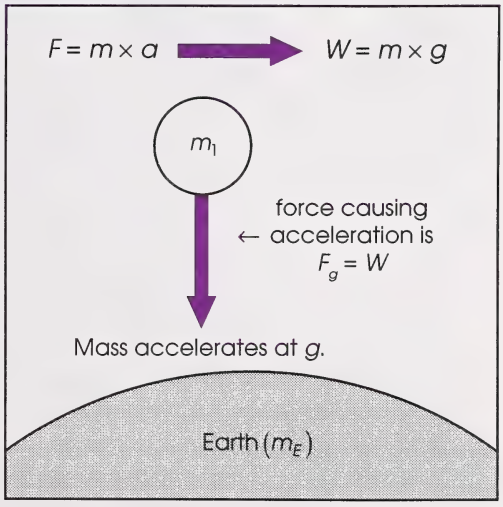
26. a. If another name for the force of gravitational attraction (F_g) on a mass is the weight of an object (W), and another name for the acceleration of a falling object (a) is acceleration due to gravity (g), then convert the equation of Newton's Second Law to derive an equation to solve for the weight of an object.

$$F = m \times a$$
$$\downarrow \quad\quad \downarrow$$
$$\_\_ = m \times \_\_$$

    b. Use the previous equation to solve the weight of a student whose mass is 50.0 kg in a place where the acceleration due to gravity is 10.0 m/ s^2.

Check your answers by turning to the Appendix, Section 3: Activity 3.

Newton's Second Law of Motion and the phenomenon of an apple falling from a tree led Newton to one of his most important discoveries – the concept of gravity. He realized that the acceleration of a falling object is caused by a force of attraction between the masses of the object and the Earth, and that this force is called the force of gravitational attraction or the weight of an object.



At this point Newton realized that one of the most important properties of an object, the mass of an object, can really have two faces.

VISIONS

Read from the bottom of page 429 to the middle of page 430 of *Visions 2;* then answer the following questions.

27. a. Newton's First Law defined the mass of an object as the property of an object that resists a change in uniform velocity or the inertia of an object. Newton's Second Law now states that an object can have two kinds of masses. What are these two masses?

    b. What is the definition of an inertial mass?

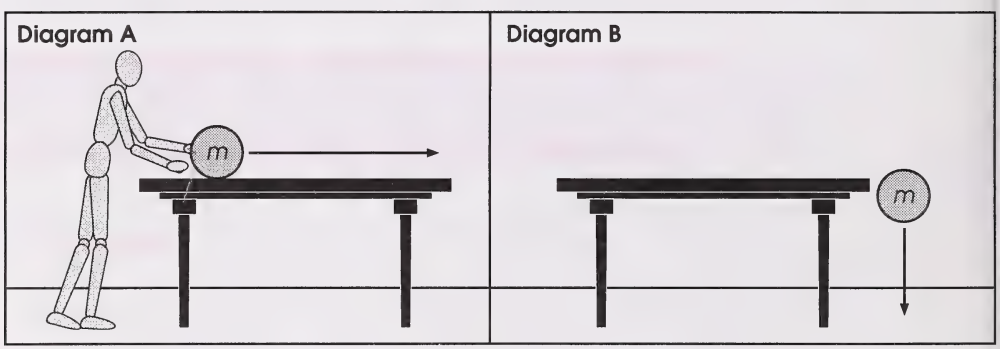
    c. What formula is generally used to calculate inertial mass?

    d. What is the definition of a gravitational mass?

    e. What formula can be used to calculate the gravitational mass?

    f. Are these masses really the same?

28. To see how this applies in a problem-solving situation, study the following illustrations and answer the questions accompanying them.



    a. In Diagram A, an unbalanced force of 10.0 N pushes on a mass (m) in the direction shown, causing it to accelerate in the same direction as the force is applied at $10.0\ m/s^2$. Calculate the inertial mass of the object.

    b. In Diagram B, this same mass (m) is now being attracted to the Earth. The unbalanced gravitational force acting downward on the object is 9.81 N, causing the object to accelerate down at $9.81\ m/s^2$. Calculate the gravitational mass of the object.

Check your answers by turning to the Appendix, Section 3: Activity 3.

There is an important distinction between the mass of an object and the weight of an object. To clarify this distinction, complete the following questions with regard to both mass and weight.

29. Compare mass and weight in terms of the following questions. Set up your answer in the form of a chart with the headings question, mass, and weight across the page.

    a. What is the definition of each quantity?

    b. What is the symbol of each quantity?

    c. What are their units?

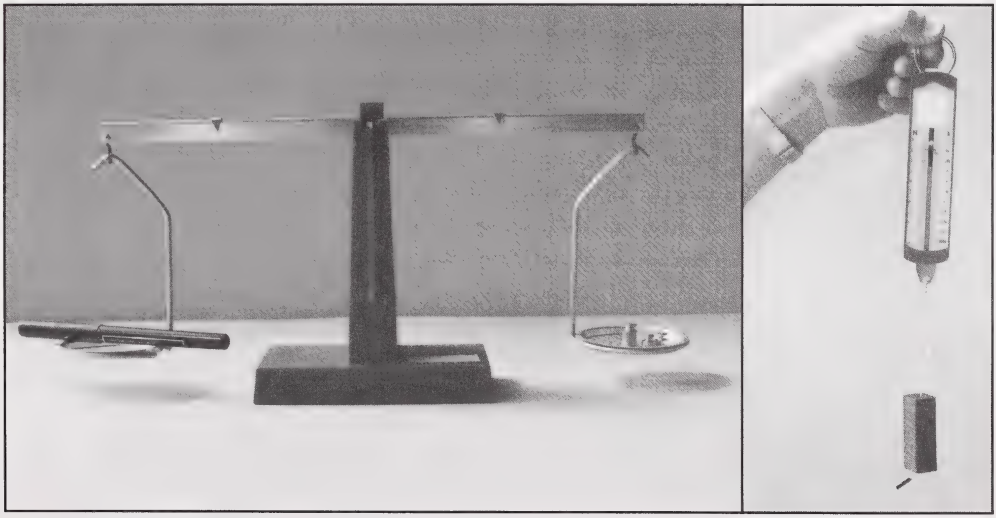
    d. Determine the mass and the weight of a 1.0 kg mass in a place where g is $10.0\ m/s^2$.

    e. Will this mass and weight be the same on the moon? Why?

Check your answers by turning to the Appendix, Section 3: Activity 3.

VISIONS

Since the mass of an object is different than the weight of an object, there must be different measuring devices to determine their values. Read pages 424 and 425 of *Visions 2*; then answer the following questions.



30. Which device would be used to measure the mass of an object?

31. Which device would be used to measure the weight of an object?

32. What units should each device be measured in?

33. Even though the spring scale is measuring the weight of an object and should be measured in newtons (N), these scales are often labelled in kilograms (kg), a mass unit.

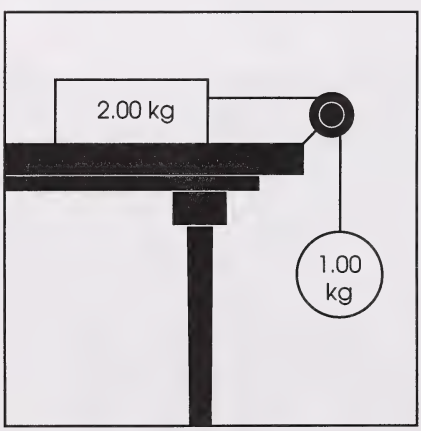
    a. Are they measuring inertial or gravitational mass?

    b. How can you convert this measurement to proper units?

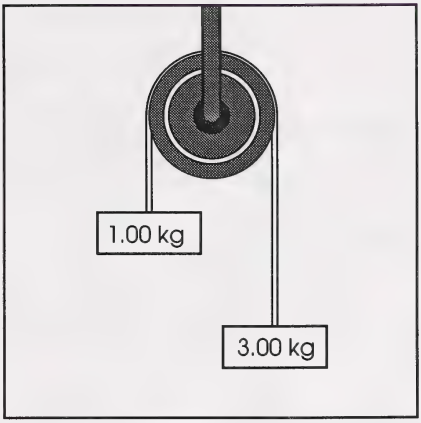
Check your answers by turning to the Appendix, Section 3: Activity 3.

This distinction between mass and weight can now be used to solve more complicated problems involving Newton's Second Law. (Recall: The weight of an object is a force.)

34. A 2.00 kg mass is resting on a frictionless table and is attached to a 1.00 kg falling mass. Calculate the acceleration of the system in the following diagram $\left(g = 9.81\,\text{m/s}^2\right)$.



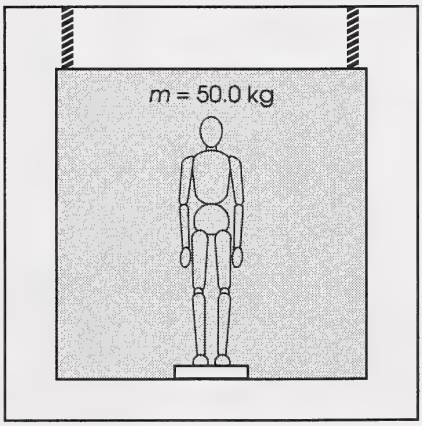
35. Two masses of 1.00 kg and 3.00 kg are attached by a string over a frictionless pulley. Calculate the acceleration of the system in the diagram $\left(g = 9.81\,\text{m/s}^2\right)$. (Hint: What is the unbalanced mass?)



36. Suppose you were standing on a spring scale in an elevator at a place where $g = 9.81\,\text{m/s}^2$.

    a. What would the scale read if the elevator was at rest and your mass was 50.0 kg? (Give the reading in newtons.)

    b. What if the elevator cable broke and the elevator, the scale, and you were falling at $g = 9.81\,\text{m/s}^2$. What would the scale read now?



VISIONS

Read from the middle of page 430 to page 432 of *Visions* 2.

37. What would the feeling of falling in an elevator if the cable broke be called?

38. Will your velocity in free fall increase at the start?

39. Will you reach a maximum speed?

40. What will your maximum falling speed be called?

41. What causes you to reach a terminal velocity?

Check your answers by turning to the Appendix, Section 3: Activity 3.

The applications of Newton's Second Law of Motion are many and varied, and you are able to perform many calculations much the same way as Newton did 300 years ago. The implications of the second law in defining gravity and thus being able to describe planetary motion using a heliocentric model, won Newton everlasting importance in the field of science. But his studies of motion were not complete. In the next activity you will study Newton's Third Law of Motion.

Activity 4: Newton's Third Law of Motion

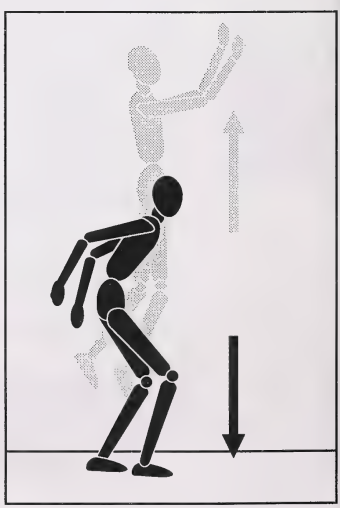


Once upon a time a farmer wanted to deliver a cart loaded with farm produce to town. The farmer hitched up a horse to the cart and with a confident voice commanded it to "Giddy-up!" But the horse, being very intelligent, refused to budge. When the farmer began to plead, the horse neighed that it was useless to pull because, due to Newton's Third Law, no matter how hard it pulled, the cart would never move. Is the horse right?

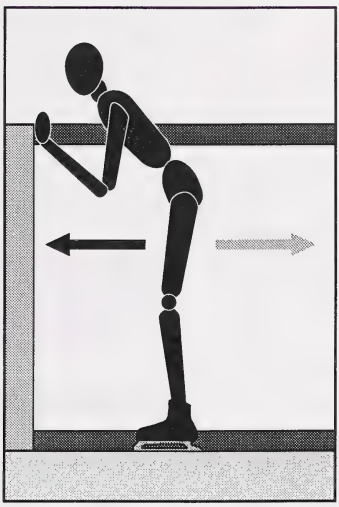
In this activity you will analyse Newton's Third Law of Motion to see if this horse is correct.

As Newton was formulating his first and second laws of motion, he realized that there was a necessity for a third law. Consider the following situations.

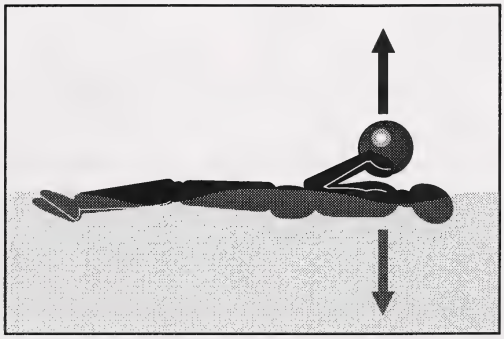
1. If you want to jump up, you exert a force downward with your body and legs on the surface of the Earth. Newton's Second Law states that since this force is downward, your mass should accelerate downward. But in what direction are you accelerating?



2. Imagine you are on ice skates in an ice arena, and you are standing facing the side boards. Suddenly, you push forward against the boards. If your force is towards the boards, which way do you move?



3. Imagine you are floating in a swimming pool and you throw a ball upward. If your force is upward, which way do you move?



Check your answers by turning to the Appendix, Section 3: Activity 4.

The necessity for the third law appeared when Newton realized that whenever an object (A) exerts a force on another object (B), object A will also experience a force.

4. If you push against a rigid wall with a force of 10.0 N, do you feel a force of the wall on your hands? What do you call the force that the wall exerts on your hands?

VISIONS

Read page 441 and 442 of *Visions 2;* then answer the following questions.

5. If you push against a rigid wall with a force of 10.0 N, what is this force called?

6. If the wall pushes back on your hand with a force, what is this force called?

7. Are these forces equal in magnitude? How do you know?

8. What are these two forces called when considered together?

9. State two ways these forces are different.

10. State Newton's Third Law using action-reaction forces.

Check your answers by turning to the Appendix, Section 3: Activity 4.

In mathematical form, Newton's Third Law may be written as follows:

negative indicates an opposite direction

$$\vec{F}_{AB} = -\vec{F}_{BA}$$

the force of object A on object B (action force)

the force of object B on object A (reaction force)

Thus, every object exerting an action force will experience an equal but opposite reaction force.

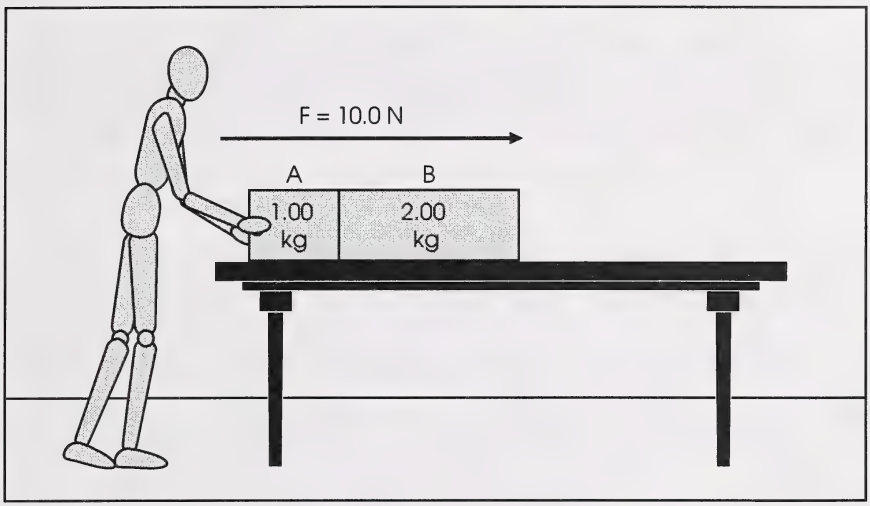
VISIONS

11. Study Figure 11.13 on page 442 of *Visions 2*, and list the action force and the reaction force for each example. You may wish to set up a chart for your answer.

12. State which is the action force and which is the reaction force in the horse and cart paradox.

13. The horse appears to understand Newton's First and Second Laws quite well, but it doesn't fully understand Newton's Third Law. The horse thinks that if it applies a force to the cart, the cart will exert the same but opposite force on him; thus, the two forces will always cancel each other out, resulting in no motion. Why is the horse wrong?

14. Newton's Third Law always involves two forces acting on two different objects. Use Newton's Second Law and Newton's Third Law to analyse the following situation.



a. A force of 10.0 N in the direction shown in the previous diagram is pushing on two blocks of wood (A and B) on a frictionless surface. What is the acceleration of the two blocks of wood?

b. What was the force necessary to accelerate block A alone?

c. What was the force necessary to accelerate block B?

d. What is the total of the forces on blocks A and B?

e. How much is the reaction force by block A?

f. How much is the reaction force by block B?

g. What do the reaction forces by the blocks A and B on the person total?

h. If there is a reaction force of 10.0 N created by the blocks A and B, why do they accelerate?

i. If there is a reaction force of 10.0 N acting on the person by the blocks, why doesn't the person accelerate backward?

Check your answers by turning to the Appendix, Section 3: Activity 4.

Although Newton's First and Second Laws of Motion were able to describe what happens when balanced or unbalanced forces act on a specific object, Newton's Third Law was able to describe the force existing between two objects. This was essential for Newton's scheme of the universe, for if the sun was to exert a force of gravitational attraction on the Earth, causing accelerated circular motion, the Earth must also be exerting a force on the sun. This will be analysed in Module 8.

Follow-up Activities

If you had difficulties understanding the concepts in the activities, it is recommended that you do the Extra Help. If you have a clear understanding of the concepts, it is recommended that you do the Enrichment.

Extra Help



Obtain the video entitled *Force and Motion: Newton's Three Laws*, Abarr Films, ACCESS Network. This video is available from the Learning Resources Distributing Centre or through your school or local library. Watch the video and answer the questions that follow. You will find it helpful to review the questions before you watch the video.

1. How is Newton's First Law of Motion stated in this video?

2. What are three situations described in the video where the first law can be observed?

3. State Newton's Second Law of Motion.

4. What is the apparatus used to confirm Newton's Second Law called?

5. Why is this apparatus used?

6. Compare the distances between the positions of the carts in the time lapse photographs.

7. What does this imply about the velocity of the cart as it moves down the track?

8. Give another name for increasing velocity?

9. When the pulling force was doubled and tripled, what happened to the acceleration of the cart?

10. When the mass of the cart was doubled and tripled while the pulling force was kept constant, what happened to the acceleration of the cart?

11. How do the results in questions 9 and 10 compare with the result you obtained in your experiment or through your calculations using the data in Activity 2 of this section.

12. Why do you think the results in the experiment in Activity 2 were not quite the same as those from the air track apparatus?

13. How is Newton's Third Law of Motion shown in the experiment with the air track?

Check your answers by turning to the Appendix, Section 3: Extra Help.

Newton's laws can be summarized as shown.

Newton's First Law	Newton's Second Law
• There is **no** net force. • Objects have a **constant** velocity ($\vec{a} = 0$) or **uniform motion**. • In the absence of net forces, objects maintain their velocity. • Also known as the law of inertia.	• There is a net force. • Objects have a **changing** velocity **(accelerated motion)**. • A net force will cause an object to accelerate in the direction of that force, according to $\vec{F} = m\vec{a}$.

Newton's Third Law

Newton's Third Law says nothing about the type of motion an object will have. The third law simply states a relationship about forces.

- Forces always act in pairs.
- The forces in the pair are equal in size but opposite in direction.
- The forces act on different objects.
- For every action force, there is an equal but opposite reaction force, as given by $\vec{F}_{A \to B} = -\vec{F}_{B \to A}$.

14. Tell which of Newton's three laws applies in each of the following situations.

    a. A car turns its wheels on a dry road and the friction between the tires and the road enables the car to turn a corner.

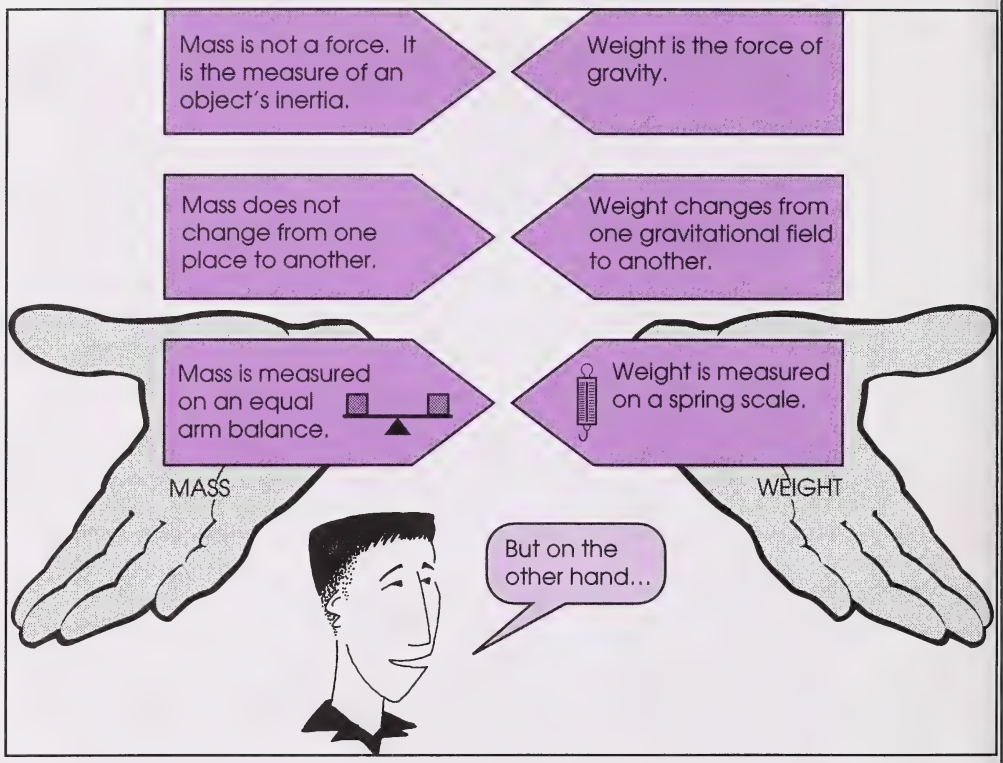
    b. A car turns its wheels on an icy road and the lack of sufficient friction causes the car to miss the curve and hit the ditch.

c. A car travelling down a highway shuts off the engine and the car eventually comes to a stop.

d. A paddle pushes against the water and causes the water to push back on the paddle.

15. Give two formulas for calculating the force of gravitational attraction between two masses.

16. Give two formulas for calculating the acceleration due to gravity caused by a mass.



17. Give the major difference between the mass of an object and the weight of an object.

18. What is the difference between G and g?

19. Define each of the following terms, and illustrate the meaning of each term by correctly using it in a complete sentence. You may wish to set up the answers in the form of a chart.

- friction
- inertia
- mass
- weight
- force

20. Calculate the acceleration of each of the following masses.

    a. An unbalanced force of 50.0 N acts horizontally on a 10.0 kg mass.



    b. A force of 50.0 N pushes horizontally on a 10.0 kg mass, but a force of friction of 10.0 N also acts on the object.



    c. Is the 10.0 kg mass a gravitational mass or an inertial mass?

    d. What is the reaction force in question 20.a.?

Check your answers by turning to the Appendix, Section 3: Extra Help.

Enrichment

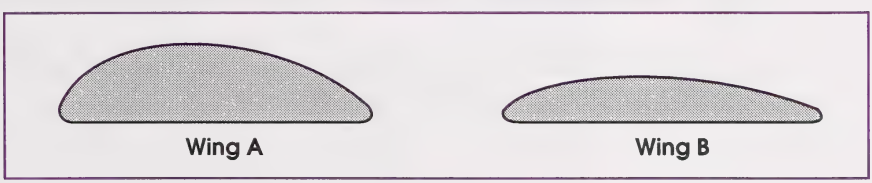
You should now be able to use the concepts from Section 3 to answer the following questions.

VISIONS

1. Do questions 5 and 8 from page 449 of *Visions* 2. Refer to the chart on page 439 to help you answer question 8.

2. Do question 2 from the projects part on page 450 of *Visions* 2.

3. Following are the designs of two airplane wings.



VISIONS

Which airplane needs a longer runway for takeoff and which airplane can fly at higher velocities? Justify and describe your answers. (Hint: Read pages 437 to 439 of your textbook.)

Check your answers by turning to the Appendix, Section 3: Enrichment.

Conclusion

You have completed Section 3 and you have seen how Newton's three laws of motion are able to describe the motion of an object under the influence of balanced or unbalanced forces, as well as the interaction of forces between two objects. The implications of these three laws are astounding, for it is difficult to describe any physical phenomenon without referring to one of these laws of motion.

ASSIGNMENT

Turn to your Assignment Booklet and do the assignment for Section 3.

MODULE SUMMARY

Upon completion of this module, you will have been introduced to a study of science that is the stepping stone to a deeper understanding of all science phenomena. The study of mechanics which includes the science of kinematics and the science of dynamics will enable you to better understand the motion of all objects around you.

The science of kinematics, or how objects move, was studied in Sections 1 and 2 of this module. From these studies you were able to distinguish and mathematically analyse uniform and accelerated motion, much the same way as Galileo did in the 1500s.

The science of dynamics, or why objects move, was studied in Section 3. From these studies you were able to see how Newton's investigation into the causes of motion led not only to Newton's three laws of motion, but also to a clearer understanding of the universe in which we live.

It is hoped that these studies have given you the basic fundamental laws necessary for you to gain an understanding of this complex world in motion.

Appendix



Glossary

Suggested Answers

Glossary

average velocity: velocity calculated over a finite time interval

displacement: a vector quantity describing a change in position

distance: a scalar quantity describing how far it is to an object or place

dynamics: a study of why objects move

force: a push or a pull exerted on an object

geocentric system (jē-ō-ˊsen-trik ˊsis-təm)**:** an Earth-centred universe with all heavenly bodies orbitting around the Earth

heliocentric system (hē-lē-ō-ˊsen-trik ˊsis-təm)**:** a sun-centred universe with the planets orbitting around the sun

inertia: the property of an object to maintain a state of rest or a state of uniform motion

instantaneous velocity: indicates the exact velocity at an exact point in time

magnitude: indicates only how far or how much

mass: the amount of matter in an object or the amount of inertia in an object

natural motion: motion of an object towards its natural place or element

position: a vector quantity describing how far it is to an object or place in a straight line and the direction

positive acceleration: acceleration of an object in which the velocity is increasing in a time interval

reference point: the starting point or origin to which the location of an object or place is compared

resultant: the single vector that has the same effect as two or more individual vectors

scalar quantities: quantities that only indicate magnitude

uniformly accelerated motion: motion of an object that is changing its velocity during a time interval

vector quantities: quantities that indicate magnitude and direction

violent motion: motion of an object which must be sustained by a force

volume: the space that an object occupies

weight: the force of gravitational attraction on an object

\a\ **h**at \ā\ **a**ge \ä\ b**a**rn \ch\ **ch**in \e\ l**e**t \ē\ b**e**, pr**e**tty \er\ c**are** \èr\ t**erm** \f\ **f**, tele**ph**one \g\ **g**o, gi**v**e \i\ **i**s \ī\ **i**ce \j\ **j**am, **g**iant \k\ **c**laim, see**k** \ng\ lo**ng** \o\ **o**dd \ō\ **o**pen \ô\ **o**rder, d**oo**r \oi\ **oi**l, b**oy** \ou\ **ou**t \s\ **s**ay, peace \sh\ ru**sh** \th\ **th**in \TH\ **th**en \u\ c**u**p \ù\ f**u**ll \ü\ r**u**le, m**o**ve \yü\ **u**se \y\ **y**et \z\ **z**ero \zh\ mea**s**ure, sei**z**ure \ə\ **a**bove, pill**a**r, take**n**, und**e**r, penc**i**l, tap**i**r, lem**o**n, fav**o**ur, circ**u**s, meas**u**re.

Suggested Answers

Section 1: Activity 1

1. a. E
   b. C
   c. G
   d. A
   e. B
   f. D
   g. H
   h. F

2. a. $v_{ave} = \frac{\Delta d}{\Delta t}$

b. $v_{ave} = \frac{\Delta d \leftarrow \text{distance travelled between two points}}{\Delta t \leftarrow \text{time taken}}$

$\uparrow$ average speed

c. The given variables are $v_{ave} = 100 \text{ km/h}$ and $\Delta d = 150 \text{ km}$.
The unknown variable is Δt.

d. $\Delta t = \frac{\Delta d}{v_{ave}}$

e. $\Delta t = \frac{150 \text{ km}}{100 \text{ km/h}}$
$= 1.50 \text{ h}$

3. You need to know where Edmonton is or in what direction to go.

4. The middle of the intersection is the reference point.

5. Two differences are as follows:

- Scalar quantities indicate only magnitude; vector quantities indicate magnitude and direction.
- Vector symbols have a vector arrow above them.

6. a. distance $(d) = 3 \text{ km}$
position $(\vec{d}) = 3 \text{ km}$, east

b. distance $(d) = 1 \text{ km}$
position $(\vec{d}) = 1 \text{ km}$, west

7. a. The two scalar quantities discussed previously are distance (d), and change in distance (Δd).

b. The two vector quantities discussed previously are position $(\vec{d})$, and displacement $(\Delta \vec{d})$.

8. a. Energy and work are two other examples of scalar quantities.

b. Force is another example of a vector quantity.

9. a. Myrna's distance travelled $(\Delta d) = 100 \text{ m}$
Jaydn's distance travelled $(\Delta d) = 50 \text{ m}$

b. Myrna's displacement $(\Delta \vec{d}) = 50 \text{ m}$, north
Jaydn's displacement $(\Delta \vec{d}) = 50 \text{ m}$, north

0. To get the heading, multiply the runway number by ten $(15 \times 10 = 150)$. Thus, the heading of an airplane landing on this runway is 150°.

1. To get the heading of the runway from the opposite end, add 180° to the given heading $(150° + 180° = 330°)$. Thus, the number of the runway on the opposite end would be 33.

2. Line A is 135° from x; line B is 290° from x; and line C is 25° from x.

3. Line A is N57°E; line B is S40°E; and line C is S75°W.

14. a. Myrna's distance travelled $(\Delta d) = 150\text{ m}$.

Jaydn's distance travelled $(\Delta d) = 50\text{ m}$.

b. Myrna's displacement $(\Delta \vec{d}) = 50\text{ m, N30°E}$.

Jaydn's displacement $(\Delta \vec{d}) = 50\text{ m, N30°E}$.

15. a. Myrna's average speed

$$v_{ave} = \frac{\Delta d}{\Delta t}$$
$$= \frac{150\text{ m}}{150\text{ s}}$$
$$= 1.00\text{ m/s (3 significant digits)}$$

Jaydn's average speed

$$v_{ave} = \frac{\Delta d}{\Delta t}$$
$$= \frac{50\text{ m}}{150\text{ s}}$$
$$= 0.33\text{ m/s (2 significant digits)}$$

b. Myrna's average velocity

$$\vec{v}_{ave} = \frac{\Delta \vec{d}}{\Delta t}$$
$$= \frac{50\text{ m}}{150\text{ s}}$$
$$= 0.33\text{ m/s, N30°E (2 significant digits)}$$

Jaydn's average velocity

$$\vec{v}_{ave} = \frac{\Delta \vec{d}}{\Delta t}$$
$$= \frac{50\text{ m}}{150\text{ s}}$$
$$= 0.33\text{ m/s, N30°E (2 significant digits)}$$

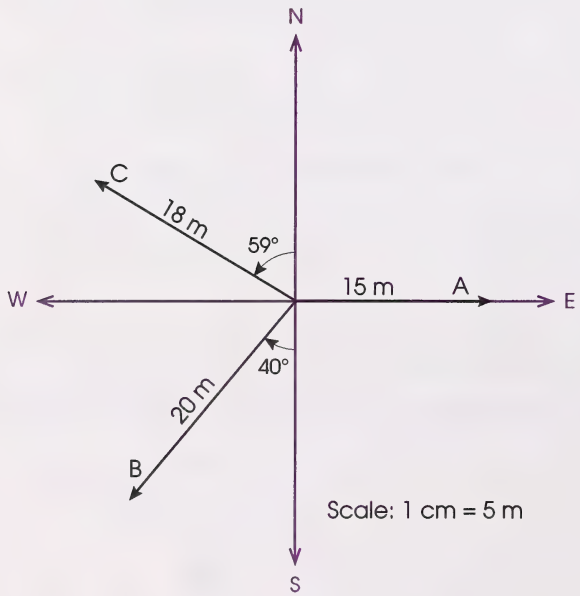
Since this question is using displacement, the average velocity is determined by the direct distance between A and B.

Section 1: Activity 2

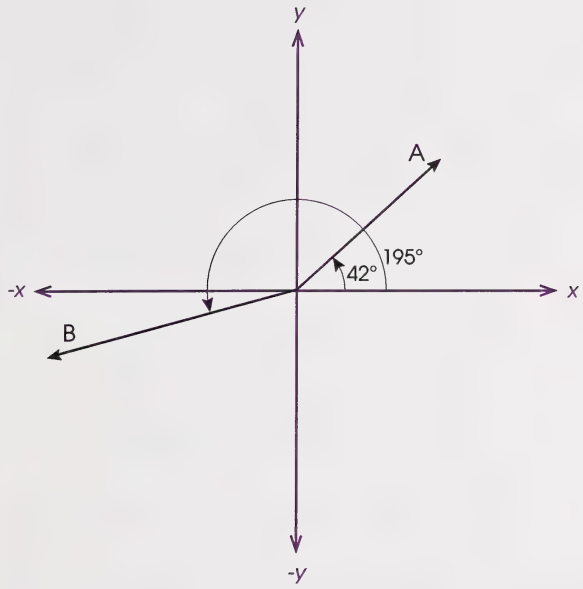
1. a. The length of the vector arrow indicates a magnitude of 10 m.

b. The arrowhead indicates a direction of north.

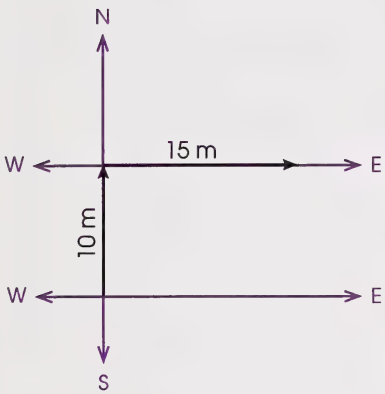
2.



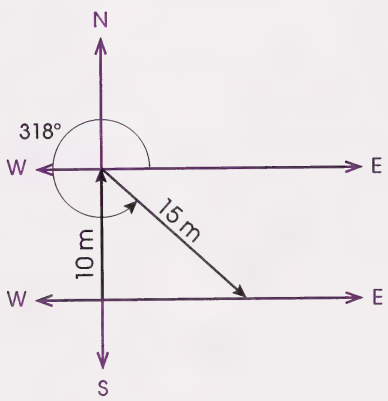
3.



4.



5.

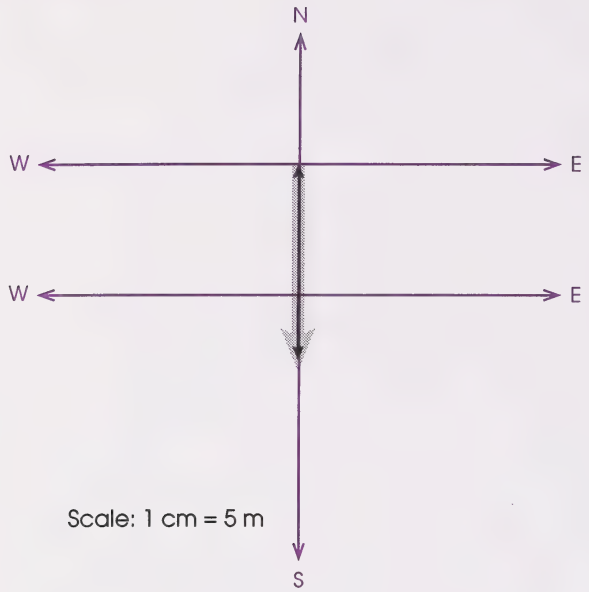


6. Draw the first vector, then draw the second vector starting from the head of the first vector.

7. The name of the rule is vector addition.

8. For each new vector added, simply draw the new vector from the head of the previous vector. To determine the resultant, you draw a vector from the tail of the first vector to the head of the last vector.

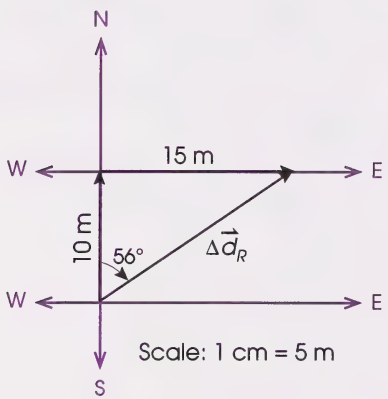
9. a.



b. The resultant is the part of the grey arrow that extends beyond the tail of the first. arrow

$\Delta\vec{d}_R$ = **5 m, south**

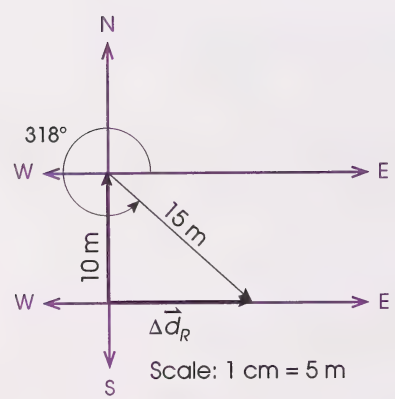
10. a.



b. The measured length of the resultant is 3.6 cm. Using the scale of 1 cm = 5 m, the length is $3.6\text{ cm} \times 5\text{ m/cm} = 18\text{ m}$.

$\Delta\vec{d}_R = 18\text{ m, N56°E}$

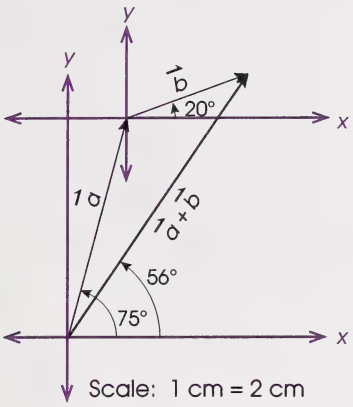
11. a.



b. The measured length of the resultant is 2.2 cm. Using the scale of 1 cm = 5 m, the length is $2.2\text{ cm} \times 5\text{ m/cm} = 11\text{ m}$.

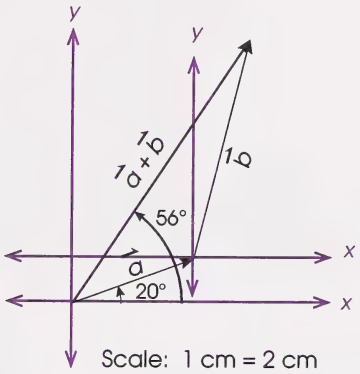
$\Delta\vec{d}_R = 11\text{ m, east}$

12. **Textbook question 1:**



$\vec{a} + \vec{b} = 9.8$ cm, at an angle of 56° to the x-axis

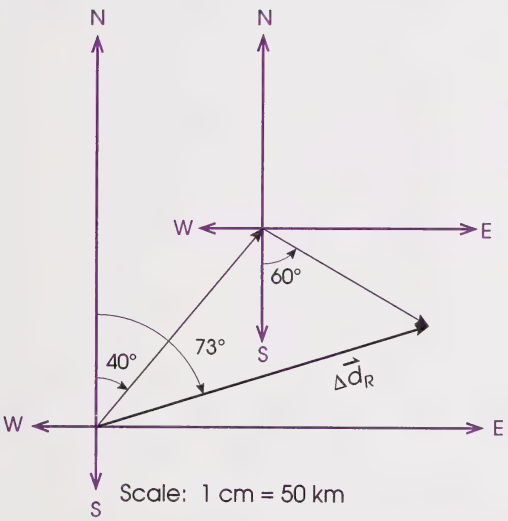
Textbook question 5:



$\vec{a} + \vec{b} = 9.8$ cm, at an angle of 56° to the x-axis

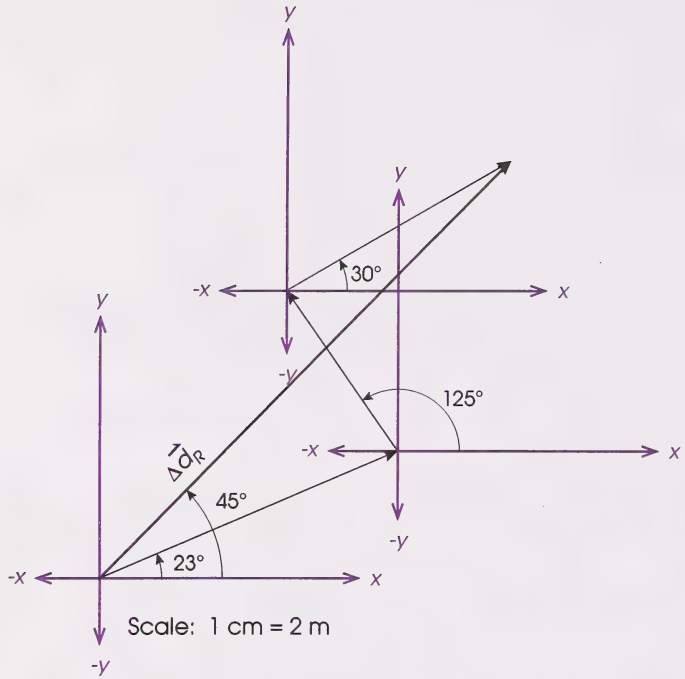
The resultants for questions 1 and 5 are the same length and at the same angle from the x-axis.

13.



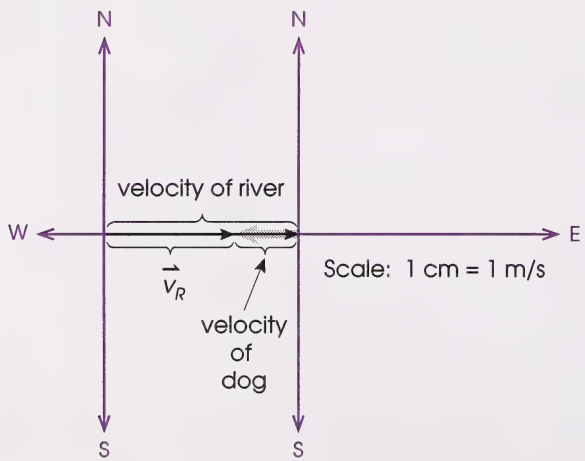
The displacement of the ship is 270 km, N73°E.

14.



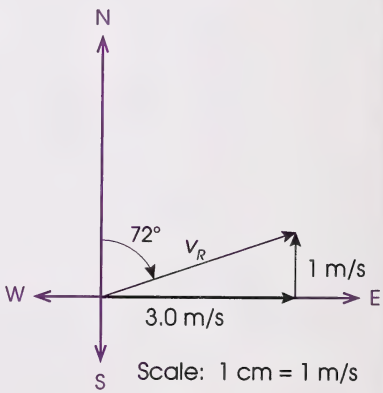
The displacement of the ball is 18 m at an angle of 45° from *x*-axis.

15. a.



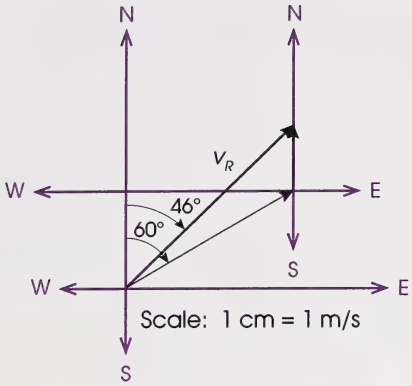
The dog is getting swept downstream at 2.0 m/s, east.

b.



The resultant velocity is about 3.2 m/s at an angle of 72°, east of north. The dog is actually heading at an angle of 72° east of north.

16.



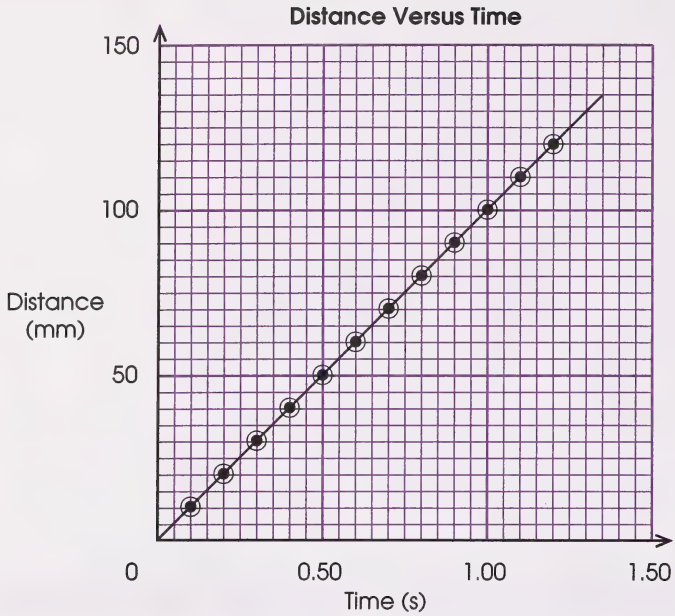
The resultant velocity is about 3.6 m/s at an angle 46°, east of north.

Section 1: Activity 3

1.

Time (s)	Distance (mm)	Time (s)	Distance (mm)
0.00	0.00	0.70	70.0
0.10	10.0	0.80	80.0
0.20	20.2	0.90	90.1
0.30	29.8	1.00	100.5
0.40	39.8	1.10	110.5
0.50	50.0	1.20	120.5
0.60	60.0		

2.



3. The graph is a straight line.

4. You can calculate the slope of the graph to find the average velocity of the object.

5. $$\text{slope} = \frac{\text{rise}}{\text{run}}$$
$$= \frac{\Delta d}{\Delta t}$$

6. a. $$\text{slope} = \frac{\text{total rise}}{\text{total run}}$$
$$= \frac{120\text{ mm} - 0\text{ mm}}{1.20\text{ s} - 0.00\text{ s}}$$ (Note: 120 mm and 0 mm are read from the graph.)
$$= \frac{120\text{ mm}}{1.20\text{ s}}$$
$$= 100\text{ mm/s}$$
$$= 1.00 \times 10^2\text{ mm/s}$$ (3 significant digits)

The average speed of the entire trip is 1.00×10^2 mm/s.

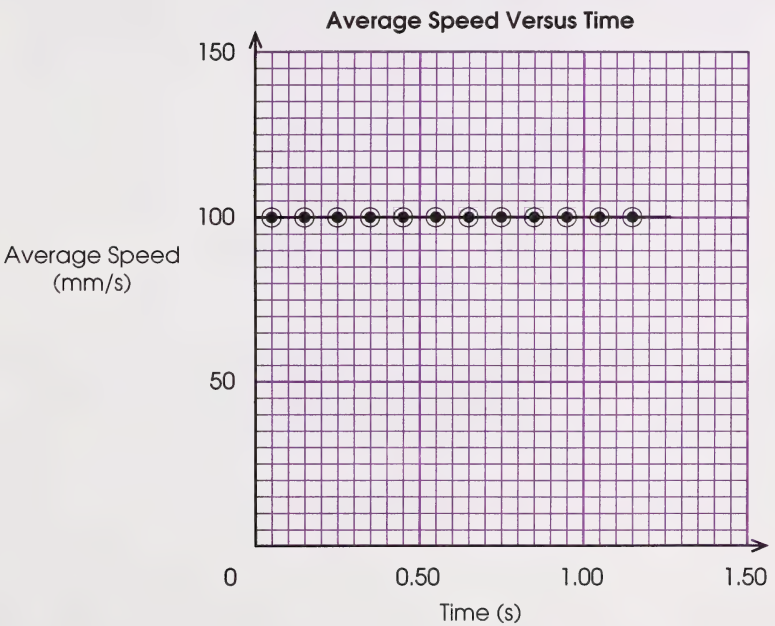
b.

Time (s)	Slope (mm/s)	Time (s)	Slope (mm/s)
0.00		0.60	
	100 or 1.0×10^2		100 or 1.0×10^2
0.10		0.70	
	100 or 1.0×10^2		100 or 1.0×10^2
0.20		0.80	
	100 or 1.0×10^2		100 or 1.0×10^2
0.30		0.90	
	100 or 1.0×10^2		100 or 1.0×10^2
0.40		1.00	
	100 or 1.0×10^2		100 or 1.0×10^2
0.50		1.10	
	100 or 1.0×10^2		100 or 1.0×10^2
0.60		1.20	

Note: In this situation you can use the values from the table instead of reading the values from the graph, since the values from the table lie on the line or very close to the line. In some intervals, the answer must be rounded. For 0.10 s to 0.20 s, the calculation is as follows.

$$\frac{20.2\text{ mm} - 10.0\text{ mm}}{0.20\text{ s} - 0.10\text{ s}} = \frac{10.2\text{ mm}}{0.10\text{ s}}$$
$$= 102\text{ mm/s}$$
$$= 1.0\times10^2\text{ mm/s}\ \text{(2 significant digits)}$$

7.



8. $\text{slope} = \dfrac{\text{rise}}{\text{run}}$

$= \dfrac{0\ \text{mm/s}}{1.20\ \text{s}}$

$= 0\ \text{mm/s/s}$

$= 0\ \text{mm/s}^2$

9. This value represents the acceleration of the object which is $0\ \text{mm/s}^2$ since it is travelling at uniform speed. (You will study acceleration in more detail in Section 2 of this module.)

10. The y-intercept indicates the average speed (100 mm/s).

11. The area under the line of the graph determines the change in distance.

12. area under the line = length × width

$= v_{ave} \times \Delta t$

$= 100\ \text{mm/s} \times 1.20\ \text{s}$

$= 120\ \text{mm}$

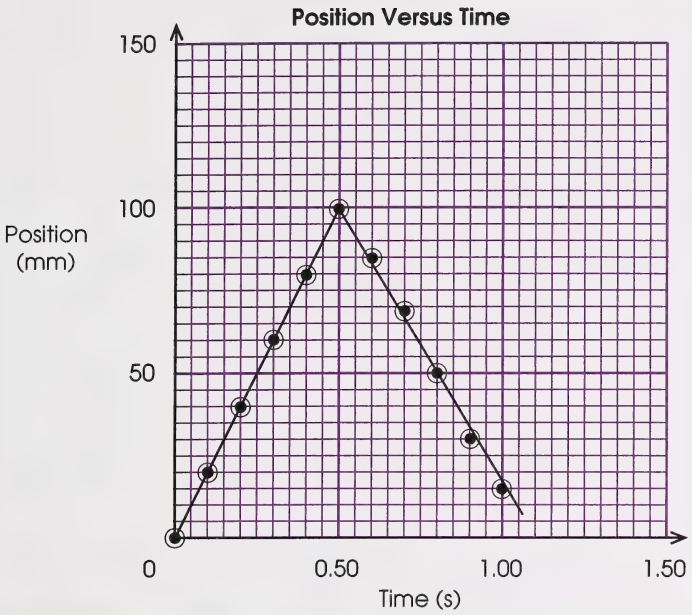
Therefore, the change in distance (Δd) is 120 mm.

13. No, there was no indication of the direction of the object.

14.

Time (s)	Position (mm)	Time (s)	Position (mm)
0.00	0.00	0.60	85.5
0.10	19.5	0.70	68.0
0.20	40.0	0.80	50.0
0.30	59.5	0.90	31.0
0.40	79.9	1.00	13.5
0.50	100.5		

15.

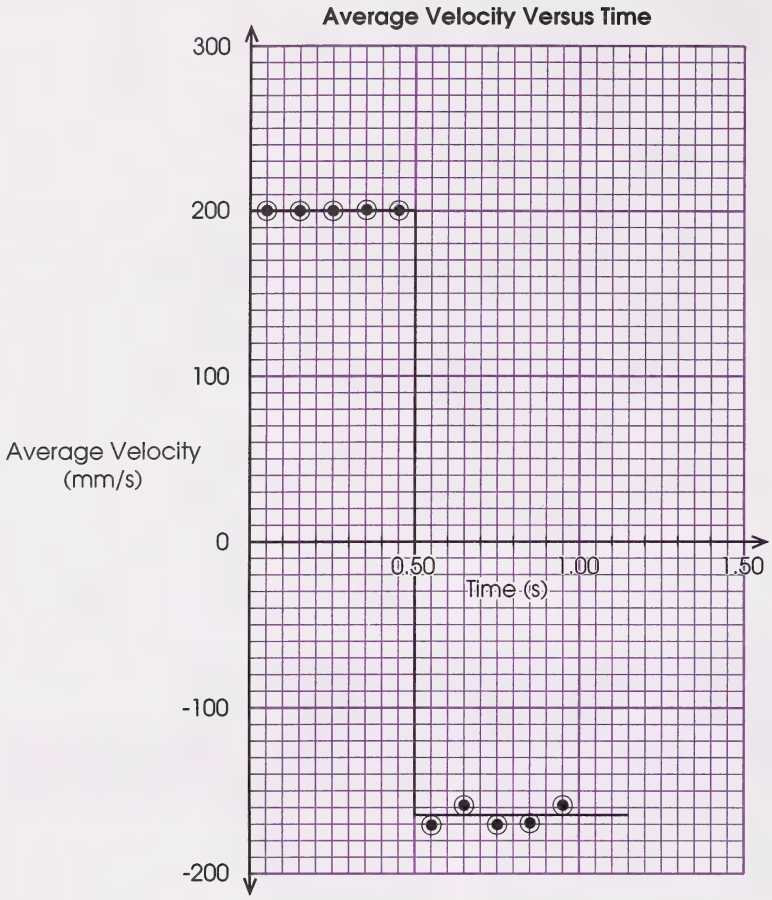


16.

Time (s)	Average Velocity (mm/s)	Time (s)	Average Velocity (mm/s)
0.00		0.50	
	200, right		170, left
0.10		0.60	
	200, right		160, left
0.20		0.70	
	200, right		170, left
0.30		0.80	
	200, right		170, left
0.40		0.90	
	200, right		160, left
0.50		1.00	

Note: Motion in one direction is labelled positive, and motion in the opposite direction is labelled negative. Thus, you can write the average velocity between 0.00 s and 0.10 s as 200 mm/s and the average velocity between 0.50 s and 0.60 s as –150 mm/s. Values are read from the graph. Read the value where the line crosses the vertical line of the desired time. For example, the value for the position at 0.60 s is 83 mm and at 0.70 s the value is 67 mm.

17.



18. $\text{slope} = \dfrac{\text{rise}}{\text{run}}$

$= \dfrac{200\ \text{mm/s} - 200\ \text{mm/s}}{0.50\ \text{s} - 0.00\ \text{s}}$

$= \dfrac{0\ \text{mm/s}}{0.50\ \text{s}}$

$= 0\ \text{mm/s}^2$

19. $\text{slope} = \dfrac{\text{rise}}{\text{run}}$

$= \dfrac{-165\ \text{mm/s} - (-165\ \text{mm/s})}{1.00\ \text{s} - 0.50\ \text{s}}$

$= \dfrac{0\ \text{mm/s}}{0.50\ \text{s}}$

$= 0\ \text{mm/s}^2$

20. The object is exhibiting uniform motion to the right (positive) and then uniform motion to the left (negative).

21. From $t = 0.00$ s to $t = 0.50$ s, the velocities were positive values; and from $t = 0.60$ s to $t = 1.00$ s the velocities were negative values.

22. area under the line = length × width

$$\Delta\vec{d} = 200 \text{ mm/s} \times 0.50 \text{ s}$$
$$= 100 \text{ mm}$$

This area determines change in position or displacement.

23. area under the line = length × width

$$\Delta\vec{d} = -165 \text{ mm/s} \times 0.50 \text{ s}$$
$$= -83 \text{ mm}$$

24. $\Delta\vec{d}_R = 100 \text{ mm} + (-83) \text{ mm}$
$= 17 \text{ mm}$

It shows that there is a smaller displacement after the ball hit the cushion. In other words, the ball lost some velocity.

Section 1: Follow-up Activities

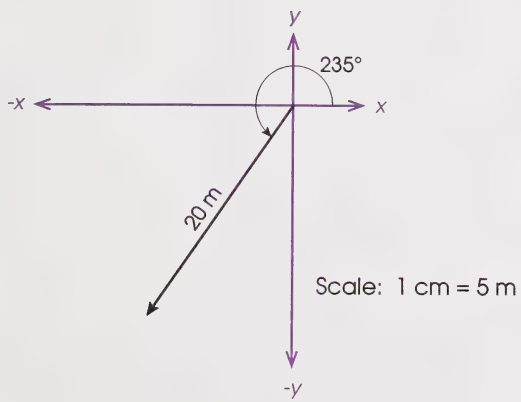
Extra Help

1. A scalar quantity only indicates magnitude. A vector quantity indicates magnitude and direction.

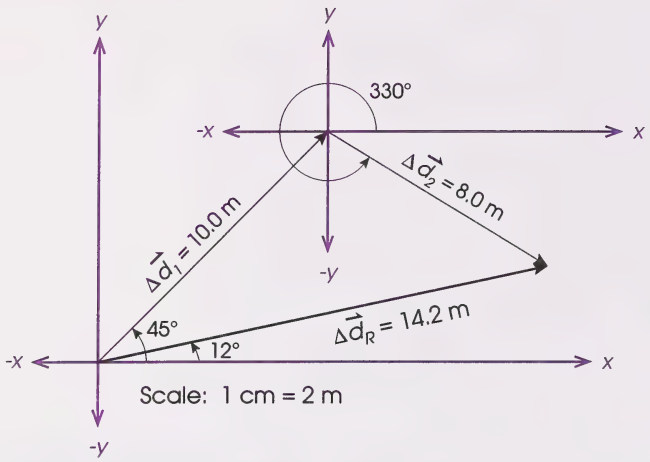
2. a. scaler
b. vector
c. vector
d. scaler
e. vector
f. scaler
g. vector
h. vector
i. scaler
j. vector
k. scaler
l. vector
m. scaler
n. vector

3. a. $\vec{v}_{ave}$
b. $\Delta\vec{d}$
c. $\vec{d}$
d. d
e. Δd
f. v_{ave}

4.



5.



The magnitude of the resultant $\left(\Delta\vec{d}_R\right)$ is 14.2 m at an angle of 12° from the x-axis.

6. a. The graph will be a straight line.

   b. It will determine the average velocity.

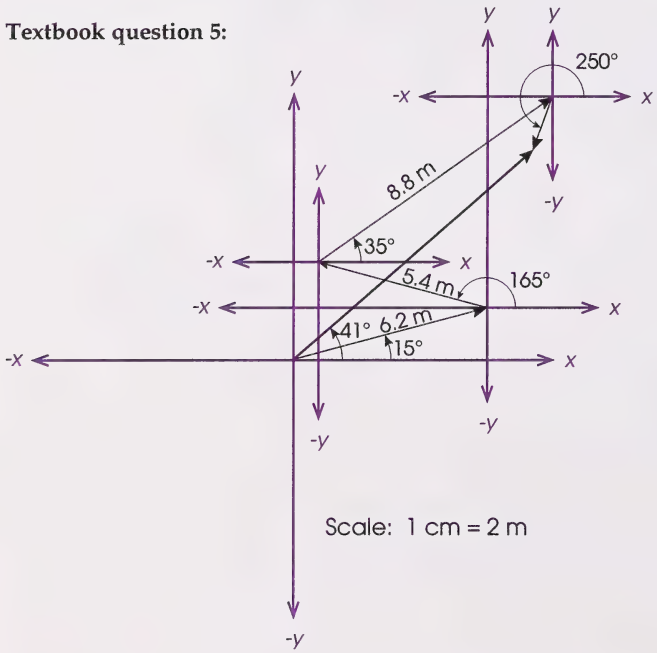
   c. The slope of the graph will always be horizontal.

   d. It will determine the displacement.

   e. i. The slope will be a negative value.
      ii. The graph will have negative values in the y-axis.

Enrichment

1. **Textbook question 5:**

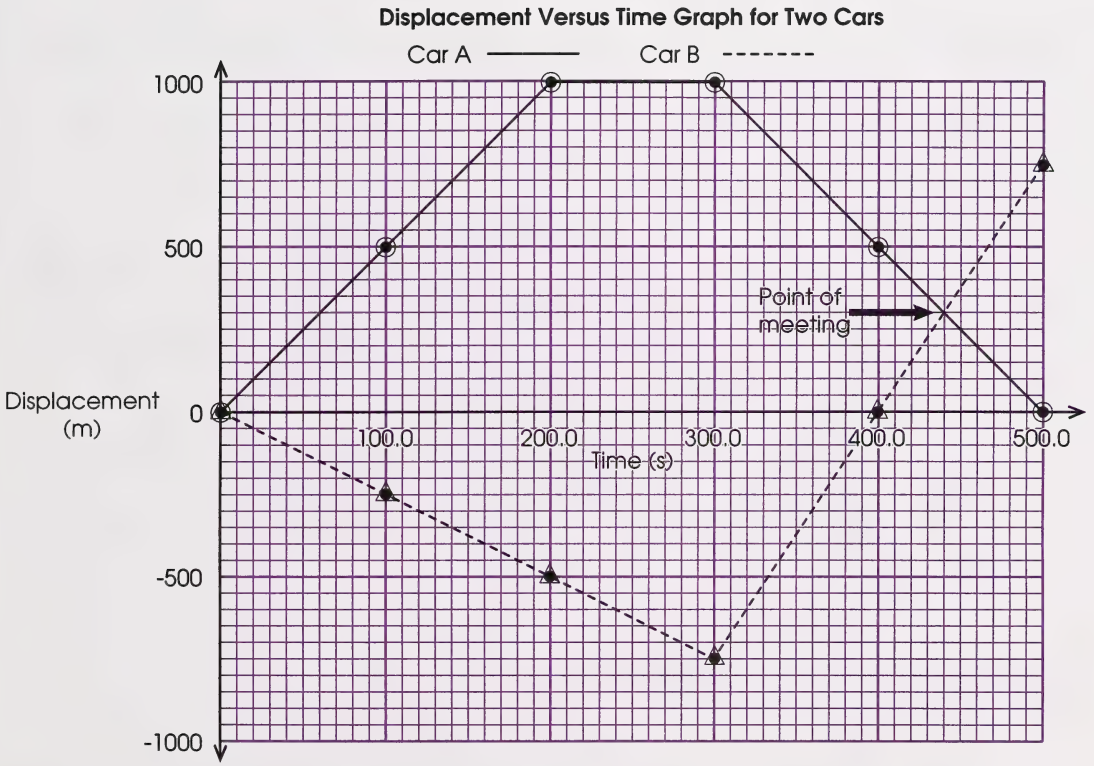


The resultant vector is 9.8 m, 41° from the x-axis.

2.

DISPLACEMENT VERSUS TIME FOR CAR A	
Time (s)	**Displacement (m)**
0	0
100.0	500
200.0	1000
300.0	1000
400.0	500
500.0	0

DISPLACEMENT VERSUS TIME FOR CAR B	
Time (s)	**Displacement (m)**
0	0
100.0	– 250
200.0	– 500
300.0	– 750
400.0	0
500.0	750



Therefore, Cars A and B meet at approximately $t = 440$ s at a position of +300 m from the start.

Section 2: Activity 1

1. If a ball rolls down a slanted table, the ball should increase its speed, or accelerate.

2. The manipulated variable is time.

3. The responding variable is distance travelled by the ball.

4. Results will vary but should be similar to the following:

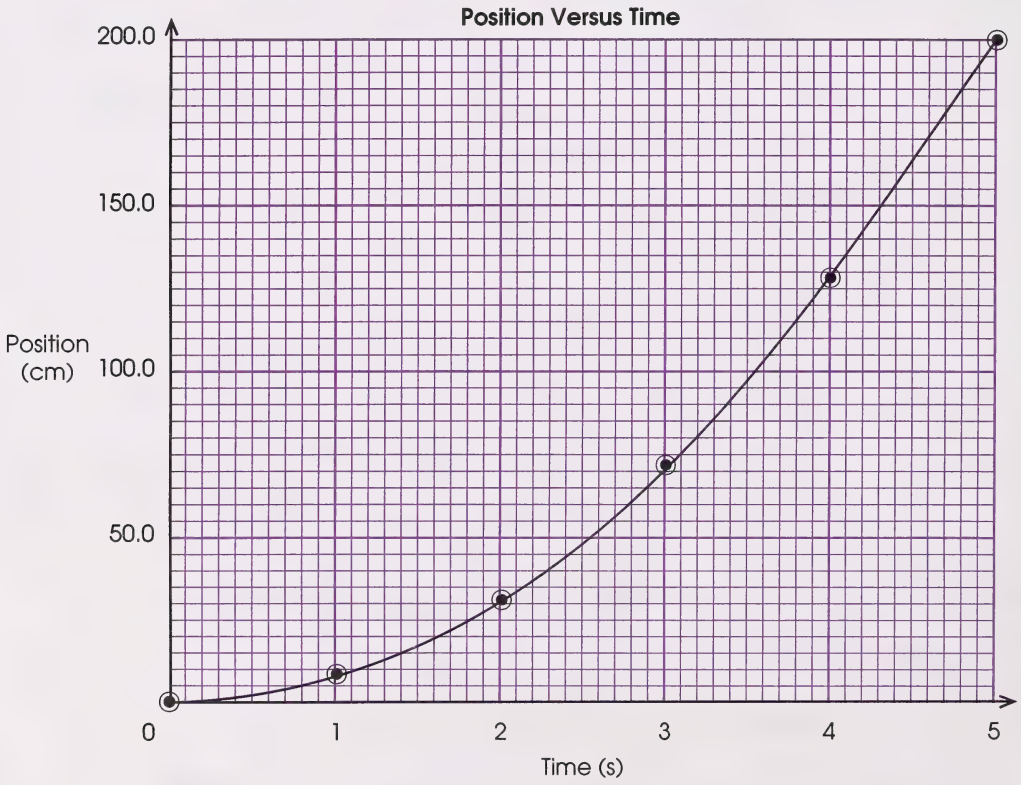
Time (s)	Position (cm)	Time (s)	Position (cm)
0	0.0	3	72.0
1	8.1	4	128.1
2	31.9	5	199.1

5. The spacings between the marks in this investigation appear to be increasing as the ball bearing rolls down the table. In the investigation involving uniform motion, the spacings between the marks were equal.

6. The velocity seems to be increasing.

7. This is called uniformly accelerated motion.

8. Graphs may vary but should be similar to the following graph.



9. The graph of the motion in this investigation appears to be curving upward, as compared to a straight line for the graph in Section 1, Activity 3.

10. The slope determines the velocity.

11. The slope appears to be getting steeper; thus, rise over run would be getting larger.

12. The velocity of the ball seems to be increasing at a regular rate.

Section 2: Activity 2

1.

Time (s)	Average Velocity (cm/s)
0.0	
	8.1
1.0	
	23.8
2.0	
	40.1
3.0	
	56.1
4.0	
	71.0
5.0	

2. a. It must be travelling slower at $t = 0.0$ s.

   b. It must be travelling faster than 8.1 cm/s at $t = 1.0$ s.

   c. The ball must be travelling exactly 8.1 cm/s at the midpoint of the first interval, $t = 0.5$ s.

3. It is an instantaneous value since this is the exact speed at the exact time you looked at the speedometer.

4. The velocity is 100 km/h, north.

5. $\vec{v}_{ave} = \dfrac{\Delta \vec{d}}{\Delta t}$

$= \dfrac{200.0 \text{ km}}{2.10 \text{ h}}$

$= 95.2 \text{ km/h}$ (3 significant digits)

6.

Time (s)	Instantaneous Velocity (cm/s)
0.0 s	0.0
1.0 s	16.2
2.0 s	31.4
3.0 s	48.8
4.0 s	63.4
5.0 s	78.6

7.

Time (s)	Change in Velocity (cm/s)
0.0	
	16.2
1.0	
	15.2
2.0	
	17.4
3.0	
	14.6
4.0	
	15.2
5.0	

8. The average rate of change in velocity is calculated as follows:

$$\begin{array}{r} 16.2 \\ 15.2 \\ 17.4 \\ 14.6 \\ \underline{15.2} \\ 78.6 \end{array} \quad \text{and} \quad \frac{78.6 \text{ cm/s}}{5} = 15.7 \text{ cm/s every 1 s}$$

9. The average rate of change in velocity is 15.7 cm/s every 1.0 s. This is the average acceleration of 15.7 cm/s/s or 15.7 cm/s^2.

10. The ball is accelerating uniformly.

11. $$\vec{a} = \frac{\vec{v}_f - \vec{v}_i}{\Delta t}$$
$$= \frac{20.0 \text{ m/s} - 0.0 \text{ m/s}}{4.00 \text{ s}}$$
$$= 5.00 \text{ m/s}^2 \text{ in the given direction}$$

12. No, the object could also slow down. Any change in velocity is an acceleration.

13. $$\vec{a} = \frac{\vec{v}_f - \vec{v}_i}{\Delta t}$$
$$= \frac{10.0 \text{ m/s} - 20.0 \text{ m/s}}{2.00 \text{ s}}$$
$$= -5.00 \text{ m/s}^2 \text{ in the given direction}$$

14. **Textbook question 1:**

$$\vec{a} = \frac{\vec{v}_f - \vec{v}_i}{\Delta t}$$
$$= \frac{35\ \text{km/h} - 10\ \text{km/h}}{1.5\ \text{min}}$$
$$= 17\ \text{km/h/min} \quad \text{(multiply by 60 min/1 h)}$$
$$= 1.0 \times 10^3\ \text{km/h}^2 \quad \text{(2 significant digits)}$$

Textbook question 2:

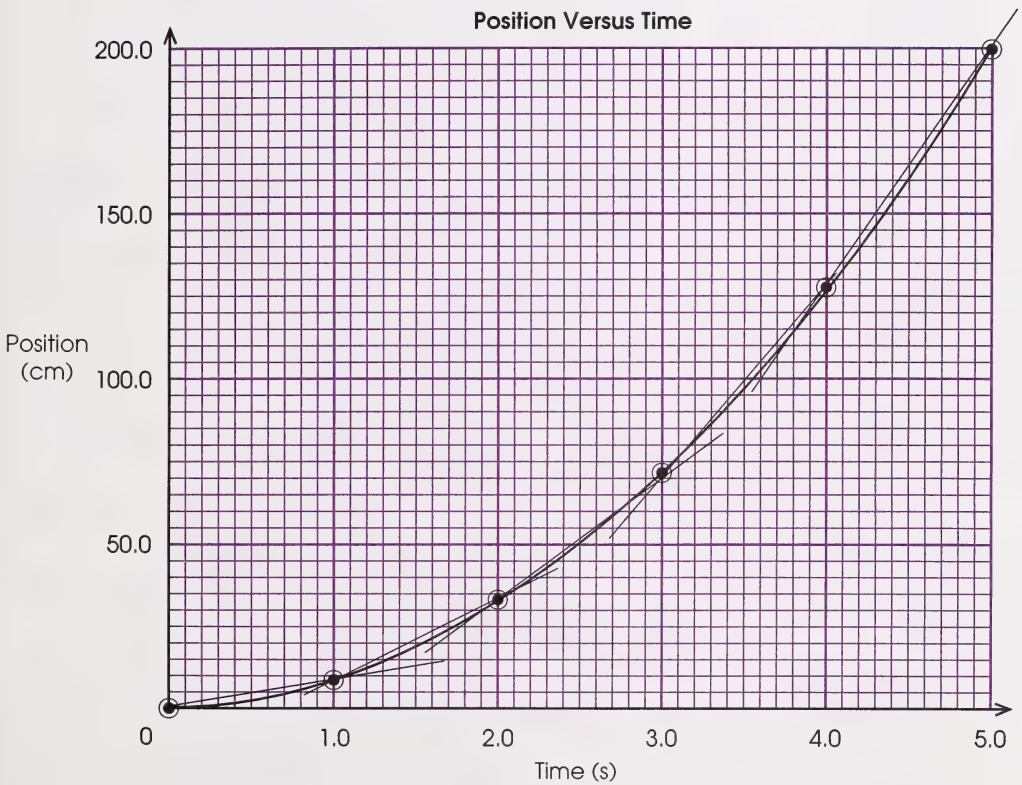
$$\vec{a} = \frac{\vec{v}_f - \vec{v}_i}{\Delta t}$$
$$= \frac{0.0\ \text{m/s} - 45\ \text{m/s}}{4.6\ \text{s}}$$
$$= -9.8\ \text{m/s}^2 \quad \text{(2 significant digits)}$$

15. **Textbook question 1:** A negative acceleration could be termed slowing down or deceleration.

16. **Textbook question 4:** You would not be able to tell the difference between constant velocity and no motion at all. If the train slowed down, you would be able to sense the deceleration because the fluid in the semicircular canals of the ear moves and pushes on hair cells within the inner ear. This stimulates the nerve cells which the brain interprets as a change in motion.

Section 2: Activity 3

1.



2. This graph is curved, while a graph of uniform motion is a straight line.

3. The slope determines the velocity.

4. The lines are getting steeper.

5. The velocity should be increasing.

6. $\text{slope} = \dfrac{\text{rise}}{\text{run}} = \dfrac{\Delta \vec{d}}{\Delta t}$

7. The chart and calculations for each time interval are as follows:

Interval 0.0 s – 1.0 s

$$\text{slope} = \frac{\Delta \vec{d}}{\Delta t} = \frac{8.1\text{ cm} - 1.0\text{ cm}}{1.0\text{ s} - 0.0\text{ s}} = \frac{8.1\text{ cm}}{1.0\text{ s}} = 8.1\text{ cm/s}$$

Time (s)	Slope (cm/s)
0.0	
	8.1
1.0	
	23.9
2.0	
	40.1
3.0	
	56.1
4.0	
	71.0
5.0	

Interval 1.0 – 2.0 s

$$\text{slope} = \frac{\Delta \vec{d}}{\Delta t} = \frac{31.9\text{ cm} - 8.1\text{ cm}}{2.0\text{ s} - 1.0\text{ s}} = \frac{23.8\text{ cm}}{1.0\text{ s}} = 23.9\text{ cm/s}$$

Interval 2.0 s – 3.0 s

$$\text{slope} = \frac{\Delta \vec{d}}{\Delta t} = \frac{72.0\text{ cm} - 31.9\text{ cm}}{3.0\text{ s} - 2.0\text{ s}} = \frac{40.1\text{ cm}}{1.0\text{ s}} = 40.1\text{ cm/s}$$

Interval 3.0 s – 4.0 s

$$\text{slope} = \frac{\Delta \vec{d}}{\Delta t} = \frac{128.1\text{ cm} - 72.0\text{ cm}}{4.0\text{ s} - 3.0\text{ s}} = \frac{56.1\text{ cm}}{1.0\text{ s}} = 56.1\text{ cm/s}$$

Interval 4.0 s – 5.0 s

$$\text{slope} = \frac{\Delta \vec{d}}{\Delta t} = \frac{199.1\text{ cm} - 128.1\text{ cm}}{5.0\text{ s} - 4.0\text{ s}} = \frac{71.0\text{ cm}}{1.0\text{ s}} = 71.0\text{ cm/s}$$

8. The slope determines an average velocity.

9. It is travelling at this exact velocity at the midpoint of the time interval. For example, it is travelling exactly 8.1 m/s at $t = 0.5$ s.

10. a. It is travelling slower during the first half of a time interval.

    b. The slope (steepness) of the curve is less in the first half of a time interval.

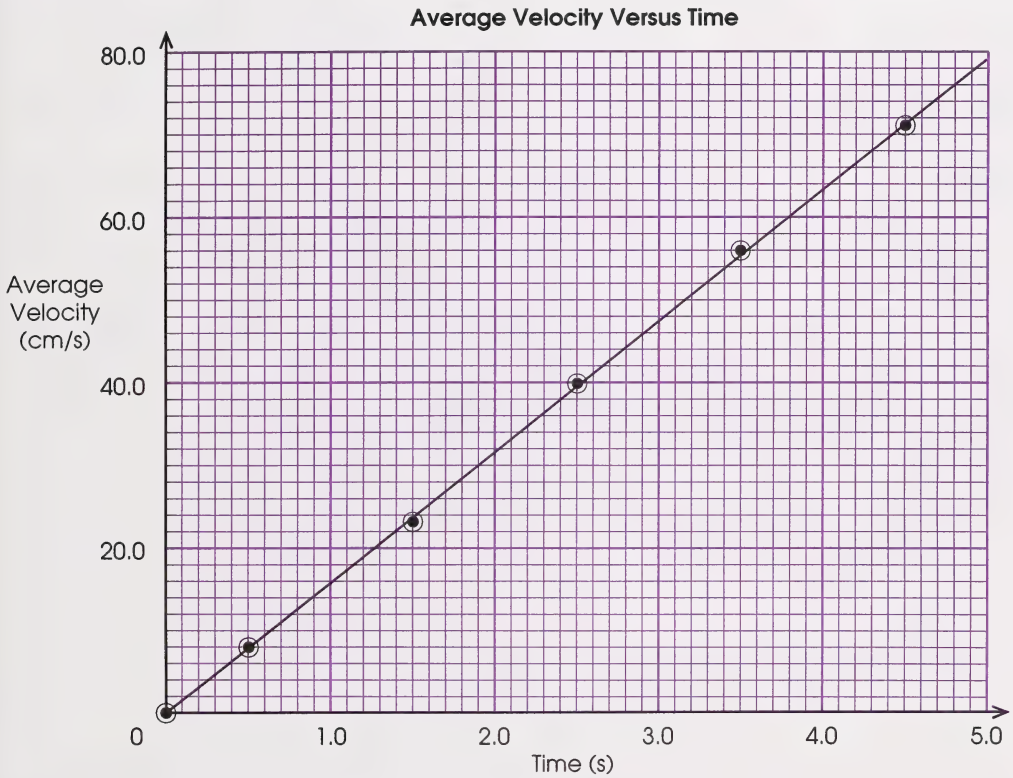
11. a. It is travelling faster during the second half of a time interval.

    b. The slope (steepness) of the curve is greater during this part of a time interval.

12. The slopes of the graph appears to be increasing.

13. The motion appears to be increasing. This is called accelerated motion.

14.



15. This graph is a straight line with a slope, as compared to a straight horizontal line for uniform motion.

16. The slope of this line determines the acceleration of the object.

17. The chart and calculations for the acceleration for each time interval are as follows. Since you are reading the values for average velocity from the graph, answers may vary slightly.

Interval 0.0 s – 1.0 s

$$\text{slope} = \frac{\Delta \vec{v}}{\Delta t}$$
$$= \frac{15.5 \text{ cm/s} - 0.0 \text{ cm/s}}{1.0 \text{ s} - 0.0 \text{ s}}$$
$$= \frac{15.5 \text{ cm/s}}{1.0 \text{ s}}$$
$$= 15.5 \text{ cm/s}^2$$

Time (s)	Acceleration (cm/s^2)
0.0	
	15.5
1.0	
	16.0
2.0	
	16.0
3.0	
	16.0
4.0	
	15.5
5.0	

Interval 1.0 s – 2.0 s

$$\text{slope} = \frac{\Delta \vec{v}}{\Delta t}$$
$$= \frac{31.5 \text{ cm/s} - 15.5 \text{ cm/s}}{2.0 \text{ s} - 1.0 \text{ s}}$$
$$= \frac{16.0 \text{ cm/s}}{1.0 \text{ s}}$$
$$= 16.0 \text{ cm/s}^2$$

Interval 2.0 s – 3.0 s

$$\text{slope} = \frac{\Delta \vec{v}}{\Delta t}$$
$$= \frac{47.5 \text{ cm/s} - 31.5 \text{ cm/s}}{3.0 \text{ s} - 2.0 \text{ s}}$$
$$= \frac{16.0 \text{ cm/s}}{1.0 \text{ s}}$$
$$= 16.0 \text{ cm/s}^2$$

Interval 3.0 s – 4.0 s

$$\text{slope} = \frac{\Delta \vec{v}}{\Delta t}$$
$$= \frac{63.5 \text{ cm/s} - 47.5 \text{ cm/s}}{4.0 \text{ s} - 3.0 \text{ s}}$$
$$= \frac{16.0 \text{ cm/s}}{1.0 \text{ s}}$$
$$= 16.0 \text{ cm/s}^2$$

Interval 4.0 s – 5.0 s

$$\text{slope} = \frac{\Delta \vec{v}}{\Delta t}$$
$$= \frac{79.0 \text{ cm/s} - 63.5 \text{ cm/s}}{5.0 \text{ s} - 4.0 \text{ s}}$$
$$= \frac{15.5 \text{ cm/s}}{1.0 \text{ s}}$$
$$= 15.5 \text{ cm/s}^2$$

18. The motion of the object is increasing at a regular rate per second. This is called acceleration.

19. The area under the line determines the displacement of the object. Note: Recall that when the starting position is zero, position is the same as displacement.

20. area under line $= \frac{1}{2} \times a \times b$

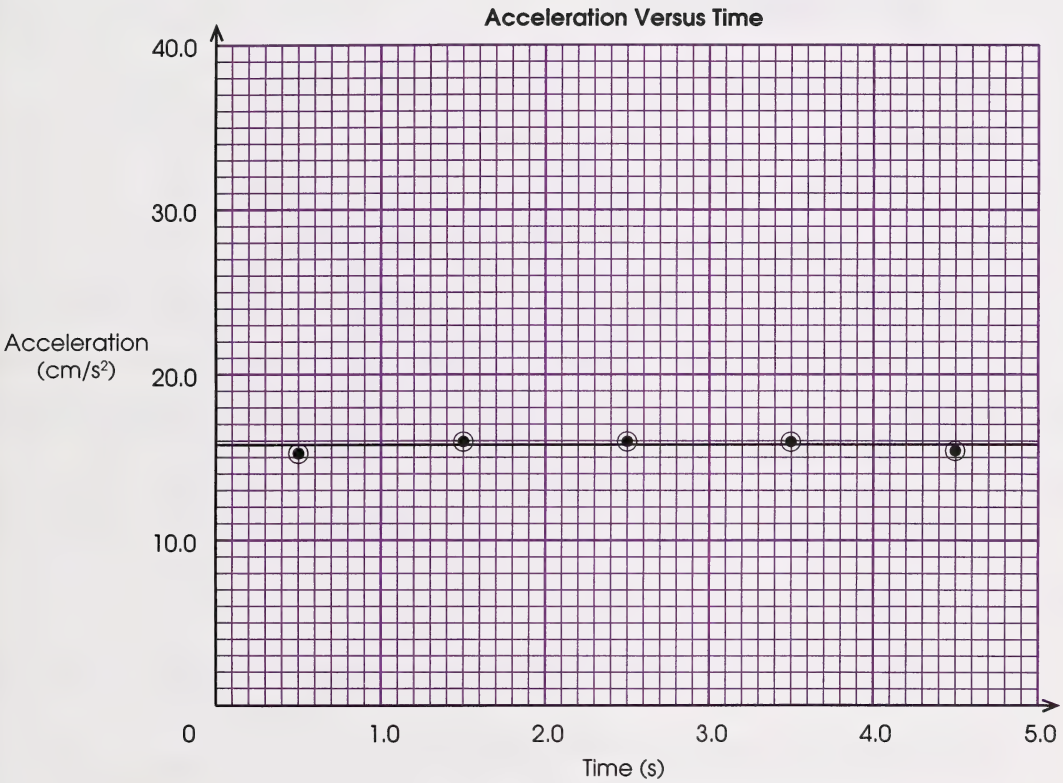
$= \frac{1}{2} \times \vec{v}_{ave} \times \Delta t$

$= \frac{1}{2} \times 79 \text{ cm/s} \times 5.0 \text{ s}$

$= 198 \text{ cm}$

21. total displacement from graph $= 198$ cm
total displacement from Table 7.6 $= 199.1$ cm
The two values are quite close.

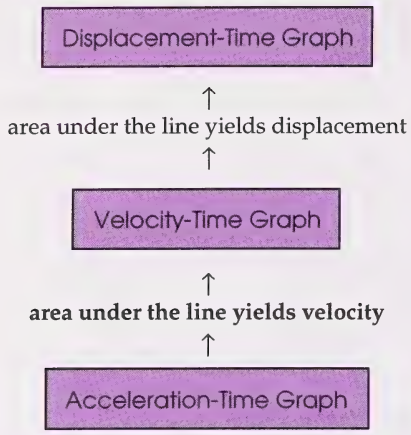
22.



23. The y-intercept is approximately 15.8 cm/s^2.

24. From the graphical method, the acceleration was approximately 15.8 cm/s^2. From the mathematical method, the acceleration was 15.7 cm/s^2 in question 8 of Section 2, Activity 2. The values are quite close.

25.



26. a. The displacement-time graph for uniform motion should be a straight line.

b. The displacement-time graph for acceleration should be a curve.

c. The velocity-time graph for uniform motion should be a straight horizontal line.

d. The velocity-time graph for acceleration should be a straight line with a positive slope.

27. a. The object is accelerating in a positive direction.

b. The object is accelerating in a negative direction.

c. The object is decelerating in a positive direction.

d. The object is decelerating in a negative direction.

e. The object is accelerating in a positive direction. or decelerating in a negative direction.

f. The object is accelerating in a negative direction. or decelerating in a positive direction.

g. The object is decelerating in a positive direction or accelerating in a negative direction.

h. The object is decelerating in a negative direction. or accelerating in a positive direction.

Section 2: Activity 4

1. Answers will vary. If you are doing the experiment in Part A, your total time elapsed and total number of ticker marks may be slightly different.

a. total time elapsed from t = start to t = finish = **0.64 s**

b. total number of ticker marks from t = start to t = finish = **25**

c. To calculate the time interval between ticker marks, use the following:

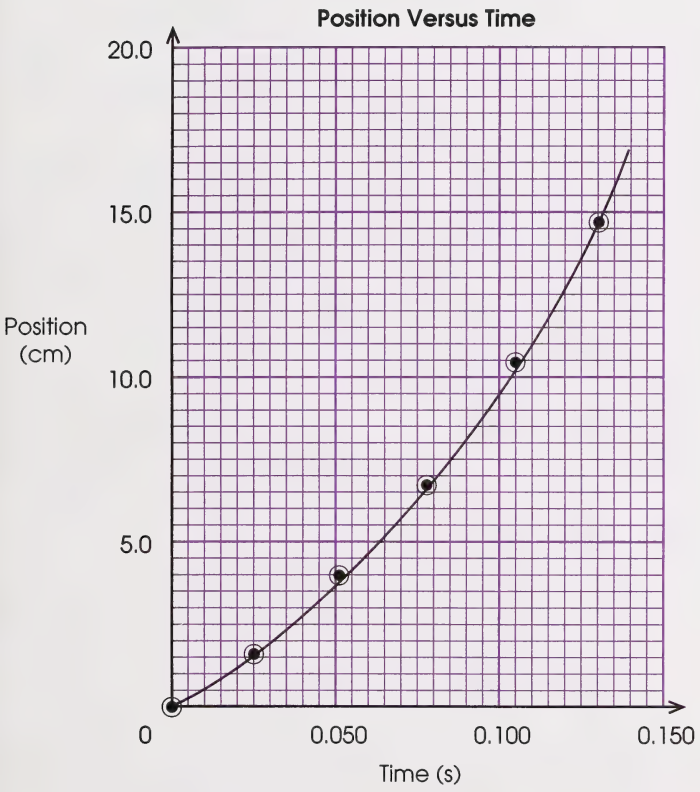
$$\frac{\text{total number of ticker marks}}{\text{time from } t = \text{start to } t = \text{finish}} = \frac{\text{1 ticker mark}}{\text{time for 1 ticker mark}}$$

time for 1 ticker mark = **0.026 s**

2.

Ticker Mark	Time (s)	Position (cm)
0	0.000	0.0
1	0.026	1.6
2	0.052	3.9
3	0.078	6.8
4	0.104	10.5
5	0.130	14.7

3.



4. The following is a chart of the average velocity at each time interval.

Time (s)	Average Velocity (cm/s)	Average Velocity (m/s)
0.000		
	6.2×10^{1}	6.2×10^{-1}
0.026		
	8.9×10^{1}	8.9×10^{-1}
0.052		
	1.1×10^{2}	1.1
0.078		
	1.4×10^{2}	1.4
0.104		
	1.6×10^{2}	1.6
0.130		

Interval 0.000 s – 0.026 s

$$\vec{v}_{ave} = \frac{\Delta\vec{d}}{\Delta t}$$
$$= \frac{1.6\text{ cm} - 0.0\text{ cm}}{0.026\text{ s} - 0.00\text{ s}}$$
$$= \frac{1.6\text{ cm}}{0.026\text{ s}}$$
$$= 62\text{ cm/s}$$
$$= 6.2\times10^{1}\text{ cm/s}$$

$$6.2\times10^{1}\text{ cm/s}\times\frac{1\text{ m}}{100\text{ cm}}$$
$$= 6.2\times10^{-1}\text{ m/s}$$

Interval 0.026 s – 0.052 s

$$\vec{v}_{ave} = \frac{\Delta\vec{d}}{\Delta t}$$
$$= \frac{3.9\text{ cm} - 1.6\text{ cm}}{0.052\text{ s} - 0.026\text{ s}}$$
$$= \frac{2.3\text{ cm}}{0.026\text{ s}}$$
$$= 89\text{ cm/s}$$
$$= 8.9\times10^{1}\text{ cm/s}$$

$$8.9\times10^{1}\text{ cm/s}\times\frac{1\text{ m}}{100\text{ cm}}$$
$$= 8.9\times10^{-1}\text{ m/s}$$

Interval 0.052 s – 0.078 s

$$\vec{v}_{ave} = \frac{\Delta\vec{d}}{\Delta t}$$
$$= \frac{6.8\text{ cm} - 3.9\text{ cm}}{0.078\text{ s} - 0.052\text{ s}}$$
$$= \frac{2.9\text{ cm}}{0.026\text{ s}}$$
$$= 112\text{ cm/s}$$
$$= 1.1\times10^{2}\text{ cm/s}$$

$$1.1\times10^{2}\text{ cm/s}\times\frac{1\text{ m}}{100\text{ cm}}$$
$$= 1.1\text{ m/s}$$

Interval 0.078 s – 0.104 s

$$\vec{v}_{ave} = \frac{\Delta\vec{d}}{\Delta t}$$
$$= \frac{10.5\text{ cm} - 6.8\text{ cm}}{0.104\text{ s} - 0.078\text{ s}}$$
$$= \frac{3.7\text{ cm}}{0.026\text{ s}}$$
$$= 142\text{ cm/s}$$
$$= 1.4\times10^{2}\text{ cm/s}$$

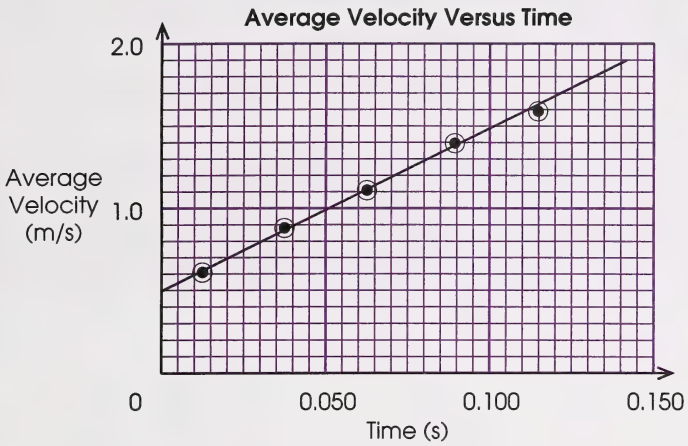
$$1.4\times10^{2}\text{ cm/s}\times\frac{1\text{ m}}{100\text{ cm}}$$
$$= 1.4\text{ m/s}$$

Interval 0.104 s – 0.130 s

$$\vec{v}_{ave} = \frac{\Delta\vec{d}}{\Delta t}$$
$$= \frac{14.7\text{ cm} - 10.5\text{ cm}}{0.130\text{ s} - 0.104\text{ s}}$$
$$= \frac{4.2\text{ cm}}{0.026\text{ s}}$$
$$= 162\text{ cm/s}$$
$$= 1.6\times10^{2}\text{ cm/s}$$

$$1.6\times10^{2}\text{ cm/s}\times\frac{1\text{ m}}{100\text{ cm}}$$
$$= 1.6\text{ m/s}$$

5. The following is the average velocity-time graph.



Note: The midpoint of these time intervals is very close to the midpoint of the actual time intervals used.

6. $$\text{total slope} = \frac{\text{total rise}}{\text{total run}}$$
$$= \frac{1.7\ \text{m/s} - 0.5\ \text{m/s}}{0.125\ \text{s} - 0.000\ \text{s}}$$
$$= \frac{1.2\ \text{m/s}}{0.125\ \text{s}}$$
$$= 9.6\ \text{m/s}^2$$

7. This represents the acceleration of the object.

8. The value obtained is fairly close to the known value.

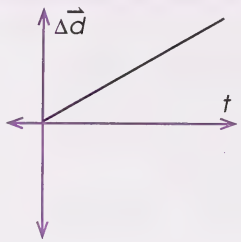
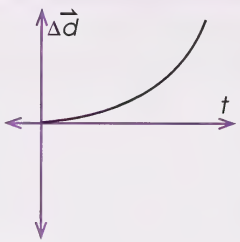
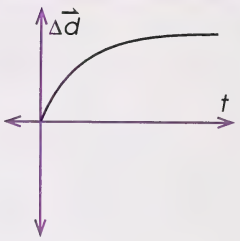
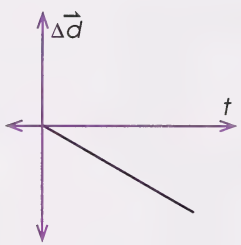
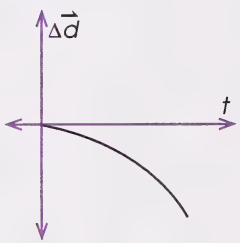
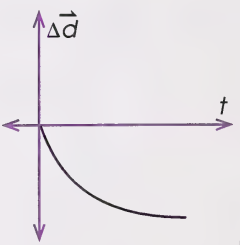
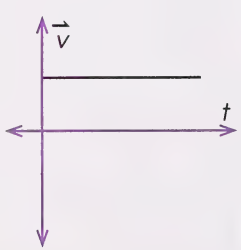
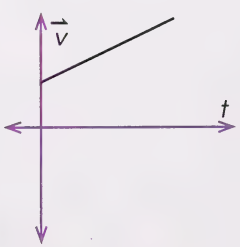
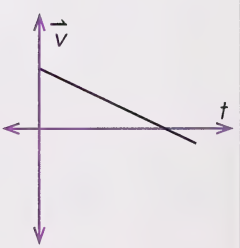
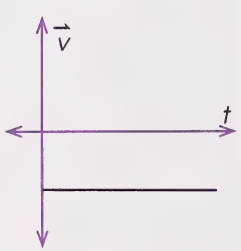
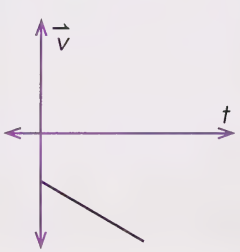
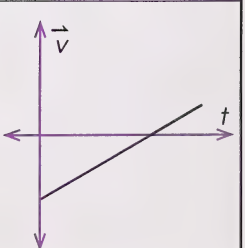
9. Refer to the answer to question 1 of Section 2, Activity 4.

10. Refer to the answers to questions 2 to 7 of Section 2, Activity 4.

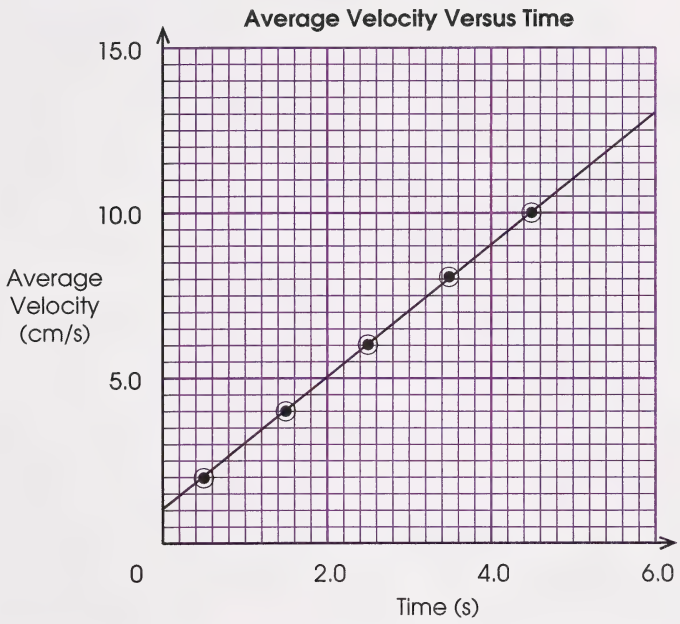
Section 2: Follow-up Activities

Extra Help

1. Answers may vary. Normally, displacement graphs start from zero; however, the velocity-time graphs need not start from the positions shown. The general shape and direction of your graphs should be similar to the ones shown.

Type of Graph	TYPE OF MOTION EXHIBITED BY AN OBJECT		
	Uniform Motion	Uniformly Accelerated Motion	Uniformly Decelerated Motion
Sketch a displacement-time graph of an object travelling in a positive direction.			
Sketch a displacement-time graph of an object travelling in a negative direction.			
Sketch a velocity-time graph of an object travelling in a positive direction.			
Sketch a velocity-time graph of an object travelling in a negative direction.			

2.

METHODS TO SOLVE FOR AVERAGE ACCELERATION	
Method 1	**Method 2**
Use formula-data substituion method in the formula $\vec{a} = \frac{\vec{v}_f - \vec{v}_i}{t}$. • $\vec{a} = \frac{4.0\text{ cm/s} - 2.0\text{ cm/s}}{1.0\text{ s}}$ $= 2.0\text{ cm/s}^2$ • $\vec{a} = \frac{6.0\text{ cm/s} - 4.0\text{ cm/s}}{1.0\text{ s}}$ $= 2.0\text{ cm/s}^2$ • $\vec{a} = \frac{8.0\text{ cm/s} - 6.0\text{ cm/s}}{1.0\text{ s}}$ $= 2.0\text{ cm/s}^2$ • $\vec{a} = \frac{10.0\text{ cm/s} - 8.0\text{ cm/s}}{1.0\text{ s}}$ $= 2.0\text{ cm/s}^2$ Therefore, average $\vec{a} = 2.0\text{ cm/s}^2$.	Use Graphical Method by finding the total slope of the graph.  Recall that the average velocity is plotted at the midpoint of the time interval. The line has been extended to the 6.0 s line. You could also read the velocity at $t = 0.0$ s and $t = 4.0$ s. $\text{total slope} = \frac{\text{total rise}}{\text{total run}}$ $= \frac{13.0\text{ cm/s} - 1.0\text{ cm/s}}{6.0\text{ s}}$ $= 2.0\text{ cm/s}^2$

3.

Question	Type of Graph		
	Displacement-Time	Velocity-Time	Acceleration-Time
What does the slope of each graph determine?	average velocity	average acceleration	
What does the area under each graph determine?		displacement	velocity

Enrichment

1. total area under line $= l \times w + \frac{1}{2}ab$

$$\vec{d} = \vec{v}_i t + \frac{1}{2} \times (\vec{v}_f - \vec{v}_i) \times t \quad \text{(Equation 1)}$$

Since $\vec{a} = \frac{\vec{v}_f - \vec{v}_i}{t}$, then $\vec{v}_f - \vec{v}_i = \vec{a}t$. (Equation 2)

Substitute Equation 2 into Equation 1.

$$\vec{d} = \vec{v}_i t + \frac{1}{2}\vec{a}t \times t \quad \text{or} \quad \vec{d} = \vec{v}_i t + \frac{1}{2}\vec{a}t^2$$

2. The data is as follows:

$\vec{v}_i = 0.0 \text{ m/s}$

$\vec{v}_f = 54.2 \text{ m/s}$

$\vec{d} = 800 \text{ m}$

$\vec{a} = ?$

The formulas for $\vec{d}$ and $\vec{a}$ are as follows:

$$\vec{d} = \vec{v}_i t + \frac{1}{2}\vec{a}t^2 \text{ and } \vec{a} = \frac{\vec{v}_f - \vec{v}_i}{t}$$

The solution is as follows:

In the formula for $\vec{a}$, solve for t.

$$\vec{a} = \frac{\vec{v}_f - \vec{v}_i}{t}$$

$$t = \frac{\vec{v}_f - \vec{v}_i}{\vec{a}}$$

Substitute t into the formula for $\vec{d}$.

$$\vec{d} = \vec{v}_i t + \frac{1}{2}\vec{a}t^2$$

$$= \vec{v}_i \left(\frac{(\vec{v}_f - \vec{v}_i)}{\vec{a}} \right) + \frac{1}{2} \times \vec{a} \left(\frac{\vec{v}_f - \vec{v}_i}{\vec{a}} \right)^2$$

Simplify the equation.

$$\vec{d} = \frac{\vec{v}_f \vec{v}_i - \vec{v}_i^{\,2}}{\vec{a}} + \frac{1}{2} \times \frac{\vec{a}(\vec{v}_f^{\,2} - 2\vec{v}_f \vec{v}_i + \vec{v}_i^{\,2})}{\vec{a}^2}$$

$$= \frac{\vec{v}_f \vec{v}_i - \vec{v}_i^{\,2}}{\vec{a}} + \frac{1}{2} \times \frac{(\vec{v}_f^{\,2} - 2\vec{v}_f \vec{v}_i + \vec{v}_i^{\,2})}{\vec{a}}$$

$$= \frac{2(\vec{v}_f \vec{v}_i - \vec{v}_i^{\,2})}{2\vec{a}} + \frac{\vec{v}_f^{\,2} - 2\vec{v}_f \vec{v}_i + \vec{v}_i^{\,2}}{2\vec{a}}$$

$$= \frac{2\vec{v}_i \vec{v}_f - 2\vec{v}_i^{\,2} + \vec{v}_f^{\,2} - 2\vec{v}_f \vec{v}_i + \vec{v}_i^{\,2}}{2\vec{a}}$$

$$= \frac{\vec{v}_f^{\,2} - \vec{v}_i^{\,2}}{2\vec{a}}$$

Solve for $\vec{a}$.

$$\vec{d} = \frac{\vec{v}_f^{\,2} - \vec{v}_i^{\,2}}{2\vec{a}}$$

$$\vec{a} = \frac{\vec{v}_f^{\,2} - \vec{v}_i^{\,2}}{2\vec{d}}$$

$$= \frac{(54.2 \text{ m/s})^2 - (0.0 \text{ m/s})^2}{2 \times 800 \text{ m}}$$

$= 1.84 \text{ m/s}^2$, in the direction the plane is moving (3 significant digits)

The average acceleration is approximately 1.84 m/s^2 in the direction the plane is moving.

Section 3: Activity 1

1. a. Since a flame has fire, it wants to reach up to its natural place. This is natural motion.

   b. An apple is composed of earth and it wants to go to its natural element, earth. This is natural motion.

   c. You must have removed the force which is necessary to sustain motion. This is violent motion.

2. The church and the ruling class at that time were very resistant to any change in ideas or thought.

3. If the circumference of a circular orbit is $2\pi r$ and the radius of Earth's orbit is 1.48×10^{11} m, the circumference of Earth's orbit is calculated as follows:

   $2 \times 3.14 \times 1.48 \times 10^{11} \text{ m} = 9.29 \times 10^{11} \text{ m}$

   Also, if Earth makes this orbit in one year or $\left(3.15 \times 10^{7} \text{ s}\right)$, then

   $$\begin{aligned} \vec{v}_{ave} &= \frac{\vec{d}}{t} \\ &= \frac{9.29 \times 10^{11} \text{ m}}{3.15 \times 10^{7} \text{ s}} \\ &= 2.95 \times 10^{4} \text{ m/s} \ \left(3 \text{ significant digits}\right) \end{aligned}$$

   Earth is travelling at approximately 2.95×10^{4} m/s or 1.06×10^{5} km/h $\left(106\,000 \text{ km/h}\right)$.

4. It must be travelling with accelerated motion since it is travelling in a curve and is always changing direction, which is a form of accelerated motion.

5. According to Aristotle, an object can only travel horizontally if there is a force applied to the object. However, Galileo's thought experiment shows that an object can travel horizontally with no forces present. This contradicts Aristotle's theory of violent motion which states that a force is required to keep an object moving.

6. A ball in horizontal motion will continue to travel horizontally at uniform motion unless a force, like friction, is applied to stop it.

7. Yes, an object at rest has a speed of 0 m/s, which is still a uniform speed.

8. An object at rest will remain at rest unless an external unbalanced force is applied.

9. Unless someone or something applies an external force to the books, they will remain on the table.

10. An object in uniform motion will continue in uniform motion in a straight line unless an external unbalanced force acts on it.

11. The ball is in uniform motion and there are no external unbalanced forces acting on it. It should continue in uniform motion.

12. An object at rest will remain at rest and an object in uniform motion will continue in uniform motion in a straight line unless an unbalanced force acts on it.

13. a. The passengers will lean back since they were at rest and want to remain at rest. No force was applied to the passengers until they were pushed by the seats.

    b. The passengers will lean forward or fly forward since they were in motion and want to continue in motion.

    c. The passengers want to continue in motion in a straight line and will lean away from the curve.

    d. The function of seat belts is to supply the external force necessary to change the motion of the passengers and overcome Newton's First Law.

14. The smaller object is easier to set in motion.

15. The smaller object is easier to stop.

16. The object in Diagram B seems to have more inertia.

17. a. The object in Diagram B is easier to stop.

    b. No, size is not the determining factor.

    c. The bowling ball has more inertia because it has more mass.

18. Mass could be the amount of inertia in an object.

19. Mass is usually measured in kilograms (kg).

20. Newton's First Law of Motion could also be called the Law of Inertia.

21. a. The tablecloth will move, but the glass will remain in one spot since an object at rest wants to remain at rest.

    b. String 2 will break since the ball has an inertia to remain at rest. If you pull slowly, this constitutes a force acting on the ball and the ball will move, breaking String 1.

Section 3: Activity 2

1. a. The resultant force is 0.

   b. Yes, it will remain at rest since no unbalanced force is applied.

   c. Yes, there are no unbalanced forces acting on the object.

   d. The forces are balanced because they are equal and act on the same object but in opposite directions. Thus, they cancel each other out.

   e. The resultant force is 2 units to the right.

   f. No, the object will be forced to move to the right.

   g. No, it will not remain at rest because there is an unbalanced force acting on it.

   h. They are unbalanced forces because there is a resulting net force on the object.

2. Accelerated motion results from a change in motion.

3. If an unbalanced force causes an object to accelerate, the two factors that must determine how much it will accelerate are **the unbalanced force applied to the object** and **the mass of the object**. Also, the amount of acceleration will increase as the **unbalanced force** increases, and the amount of acceleration will decrease as the **mass** increases.

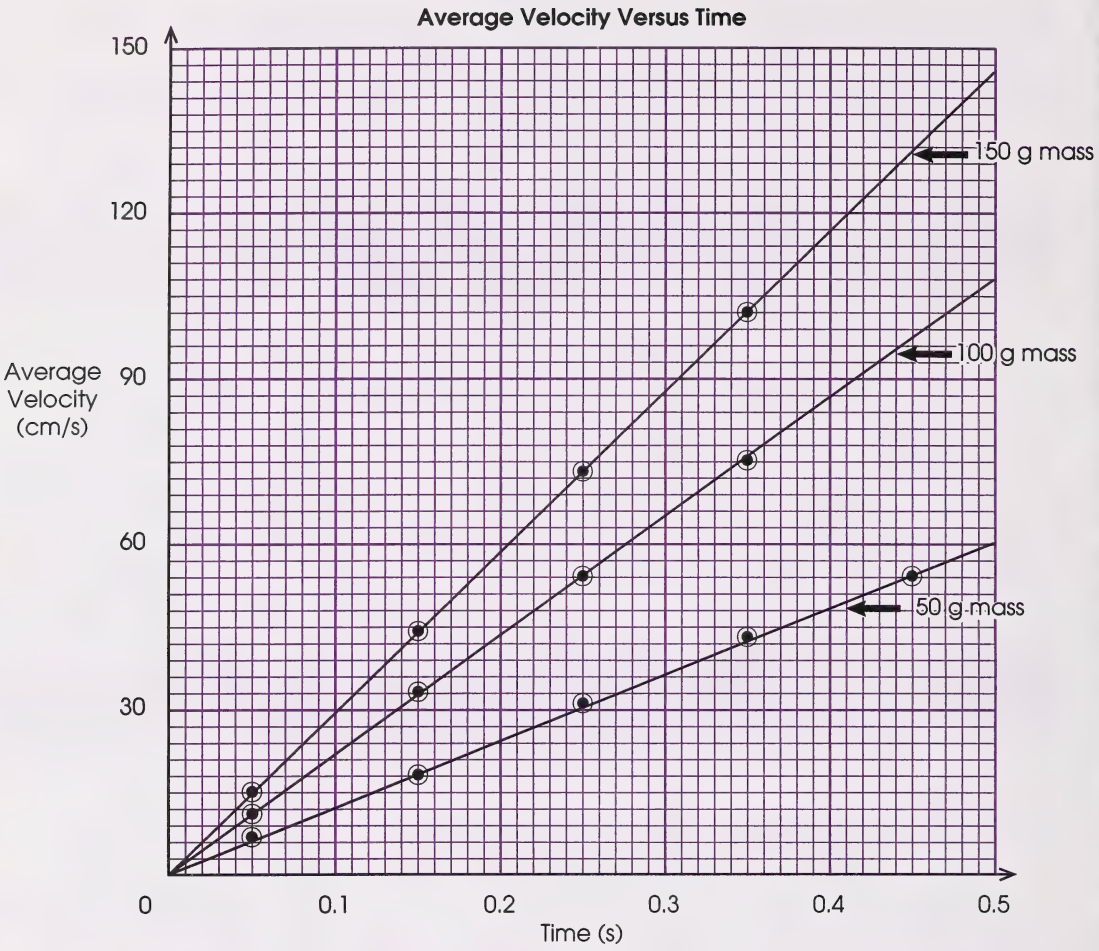
4. Charts for distance travelled and average speed of a cart accelerated by 50 g, 100 g and 150 g masses.

50 g FALLING MASS		
Time	**Displacement from Previous Dot**	**Average Velocity During Each Time Interval**
0.00 s		
	0.7 cm	$\vec{v}_{ave} = \frac{\Delta \vec{d}}{\Delta t} = \frac{0.7\text{ cm}}{0.10\text{ s}} = 7\text{ cm/s}$
0.10 s		
	1.8 cm	$\vec{v}_{ave} = \frac{\Delta \vec{d}}{\Delta t} = \frac{1.8\text{ cm}}{0.10\text{ s}} = 18\text{ cm/s}$
0.20 s		
	3.1 cm	$\vec{v}_{ave} = \frac{\Delta \vec{d}}{\Delta t} = \frac{3.1\text{ cm}}{0.10\text{ s}} = 31\text{ cm/s}$
0.30 s		
	4.3 cm	$\vec{v}_{ave} = \frac{\Delta \vec{d}}{\Delta t} = \frac{4.3\text{ cm}}{0.10\text{ s}} = 43\text{ cm/s}$
0.40 s		
	5.4 cm	$\vec{v}_{ave} = \frac{\Delta \vec{d}}{\Delta t} = \frac{5.4\text{ cm}}{0.10\text{ s}} = 54\text{ cm/s}$
0.50 s		

100 g FALLING MASS		
Time	**Displacement from Previous Dot**	**Average Velocity During Each Time Interval**
0.00 s		
	1.1 cm	$\vec{v}_{ave} = \frac{\Delta \vec{d}}{\Delta t} = \frac{1.1\text{ cm}}{0.10\text{ s}} = 11\text{ cm/s}$
0.10 s		
	3.3 cm	$\vec{v}_{ave} = \frac{\Delta \vec{d}}{\Delta t} = \frac{3.3\text{ cm}}{0.10\text{ s}} = 33\text{ cm/s}$
0.20 s		
	5.4 cm	$\vec{v}_{ave} = \frac{\Delta \vec{d}}{\Delta t} = \frac{5.4\text{ cm}}{0.10\text{ s}} = 54\text{ cm/s}$
0.30 s		
	7.5 cm	$\vec{v}_{ave} = \frac{\Delta \vec{d}}{\Delta t} = \frac{7.5\text{ cm}}{0.10\text{ s}} = 75\text{ cm/s}$
0.40 s		

150 g FALLING MASS		
Time	**Displacement from Previous Dot**	**Average Velocity During Each Time Interval**
0.00 s		
	1.5 cm	$\vec{v}_{ave} = \frac{\Delta \vec{d}}{\Delta t} = \frac{1.5\text{ cm}}{0.10\text{ s}} = 15\text{ cm/s}$
0.10 s		
	4.4 cm	$\vec{v}_{ave} = \frac{\Delta \vec{d}}{\Delta t} = \frac{4.4\text{ cm}}{0.10\text{ s}} = 44\text{ cm/s}$
0.20 s		
	7.3 cm	$\vec{v}_{ave} = \frac{\Delta \vec{d}}{\Delta t} = \frac{7.3\text{ cm}}{0.10\text{ s}} = 73\text{ cm/s}$
0.30 s		
	10.2 cm	$\vec{v}_{ave} = \frac{\Delta \vec{d}}{\Delta t} = \frac{10.2\text{ cm}}{0.10\text{ s}} = 102\text{ cm/s}$
0.40 s		

5. a.



b. slope of 50 g mass $= \frac{60 \text{ g cm/s}}{0.5 \text{ s}} = 120 \text{ cm/s}^2$

slope of 100 g mass $= \frac{108 \text{ cm/s}}{0.5 \text{ s}} = 216 \text{ cm/s}^2$

slope of 150 g mass $= \frac{145 \text{ cm/s}}{0.5 \text{ s}} = 290 \text{ cm/s}^2$

6. The slope determines the acceleration.

7. The size of the falling mass providing the unbalanced force is one of the factors.

8. The acceleration varies directly with the unbalanced force. The greater the unbalanced force, the greater the acceleration.

9. $a \propto F$

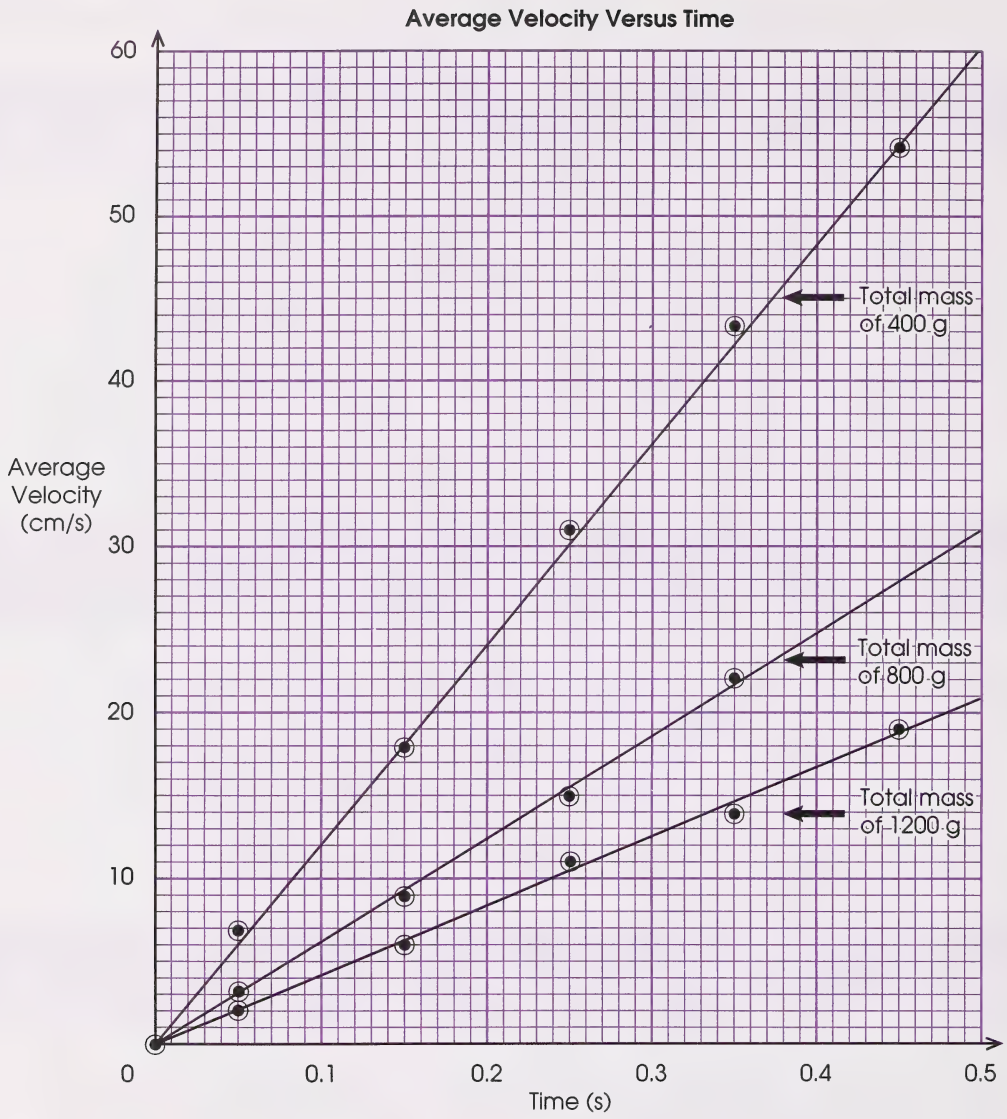
10. Charts for distance travelled and average speed for different masses of a cart accelerated by a given mass.

ORIGINAL ACCELERATING MASS (350 g + 50 g = 400 g)		
Time	**Displacement from Previous Dot**	**Average Velocity During Each Time Interval**
0.00 s		
	0.7 cm	$\vec{v}_{ave} = \frac{\Delta\vec{d}}{\Delta t} = \frac{0.7\text{ cm}}{0.10\text{ s}} = 7\text{ cm/s}$
0.10 s		
	1.8 cm	$\vec{v}_{ave} = \frac{\Delta\vec{d}}{\Delta t} = \frac{1.8\text{ cm}}{0.10\text{ s}} = 18\text{ cm/s}$
0.20 s		
	3.1 cm	$\vec{v}_{ave} = \frac{\Delta\vec{d}}{\Delta t} = \frac{3.1\text{ cm}}{0.10\text{ s}} = 31\text{ cm/s}$
0.30 s		
	4.3 cm	$\vec{v}_{ave} = \frac{\Delta\vec{d}}{\Delta t} = \frac{4.3\text{ cm}}{0.10\text{ s}} = 43\text{ cm/s}$
0.40 s		
	5.4 cm	$\vec{v}_{ave} = \frac{\Delta\vec{d}}{\Delta t} = \frac{5.4\text{ cm}}{0.10\text{ s}} = 54\text{ cm/s}$
0.50 s		

DOUBLE THE ACCELERATING MASS (800 g)		
Time	**Displacement from Previous Dot**	**Average Velocity During Each Time Interval**
0.00 s		
	0.3 cm	$\vec{v}_{ave} = \frac{\Delta\vec{d}}{\Delta t} = \frac{0.3\text{ cm}}{0.1\text{ s}} = 3\text{ cm/s}$
0.10 s		
	0.9 cm	$\vec{v}_{ave} = \frac{\Delta\vec{d}}{\Delta t} = \frac{0.9\text{ cm}}{0.1\text{ s}} = 9\text{ cm/s}$
0.20 s		
	1.5 cm	$\vec{v}_{ave} = \frac{\Delta\vec{d}}{\Delta t} = \frac{1.5\text{ cm}}{0.1\text{ s}} = 15\text{ cm/s}$
0.30 s		
	2.2 cm	$\vec{v}_{ave} = \frac{\Delta\vec{d}}{\Delta t} = \frac{2.2\text{ cm}}{0.1\text{ s}} = 22\text{ cm/s}$
0.40 s		

TRIPLE THE ACCELERATING MASS (1200 g)		
Time	**Displacement from Previous Dot**	**Average Velocity During Each Time Interval**
0.00 s		
	0.2 cm	$\vec{v}_{ave} = \frac{\Delta\vec{d}}{\Delta t} = \frac{0.2\text{ cm}}{0.1\text{ s}} = 2\text{ cm/s}$
0.10 s		
	0.6 cm	$\vec{v}_{ave} = \frac{\Delta\vec{d}}{\Delta t} = \frac{0.6\text{ cm}}{0.1\text{ s}} = 6\text{ cm/s}$
0.20 s		
	1.1 cm	$\vec{v}_{ave} = \frac{\Delta\vec{d}}{\Delta t} = \frac{1.1\text{ cm}}{0.1\text{ s}} = 11\text{ cm/s}$
0.30 s		
	1.4 cm	$\vec{v}_{ave} = \frac{\Delta\vec{d}}{\Delta t} = \frac{1.4\text{ cm}}{0.1\text{ s}} = 14\text{ cm/s}$
0.40 s		
	1.9 cm	$\vec{v}_{ave} = \frac{\Delta\vec{d}}{\Delta t} = \frac{1.9\text{ cm}}{0.1\text{ s}} = 19\text{ cm/s}$
0.50 s		

11.



12. slope of 400 g $= \frac{60 \text{ cm} / \text{s}}{0.5 \text{ s}} = 120 \text{ cm} / \text{s}^2$

slope of 800 g $= \frac{31 \text{ cm} / \text{s}}{0.5 \text{ s}} = 62 \text{ cm} / \text{s}^2$

slope of 1200 g $= \frac{21 \text{ cm} / \text{s}}{0.5 \text{ s}} = 42 \text{ cm} / \text{s}^2$

13. The slope of this graph determines the acceleration of the object.

14. Another factor that affects the acceleration is the total mass of the objects accelerating.

15. As the total mass increases, the acceleration decreases.

16. $a \propto \frac{1}{m}$

17. The unit for force is kilogram metre per second squared $\left(\text{kg} \bullet \text{m}/\text{s}^2\right)$.

Section 3: Activity 3

1. $\vec{a} = \frac{\vec{F}}{m}$

$= \frac{10.0\ \text{N}}{5.00\ \text{kg}}$

$= \frac{10.0\ \text{kg} \bullet \text{m}/\text{s}^2}{5.00\ \text{kg}}$

$= 2.00\ \text{m}/\text{s}^2$, in the direction of the force

2. total unbalanced force $= \vec{F}_R = \vec{F}_1 + \vec{F}_2$

$= 10.0\ \text{N} + 10.0\ \text{N}$

$= 20.0\ \text{N}$

$\vec{a} = \frac{\vec{F}}{m}$

$= \frac{20.0\ \text{N}}{5.00\ \text{kg}}$

$= 4.00\ \text{m}/\text{s}^2$, in the direction of the forces

3. total unbalanced force is $\vec{F}_R = \vec{F}_1 + \vec{F}_2$

$= 10.0\ \text{N} + -10.0\ \text{N}$

$= 0.0\ \text{N}$

$\vec{a} = \frac{0.0\ \text{N}}{5.00\ \text{kg}}$

$= 0.0\ \text{m}/\text{s}^2$

4. The force of friction eventually causes moving objects to stop.

5. The force of friction depends on the type of surfaces involved and the force pressing the two surfaces together (the normal force).

6. The direction of the force of friction always opposes the motion of the object.

7. Air friction opposes the motion of an airplane or the motion of a falling object. Other examples may be given.

8. A car rounding a corner or the ability to walk on ground are two examples where friction aids motion.

9. total unbalanced force $\vec{F}_R = \vec{F}_1 + \vec{F}_2$

$= 10.0\ \text{N} + (-2.0\ \text{N})$

$= 8.0\ \text{N}$

$\vec{a} = \dfrac{\vec{F}}{m}$

$= \dfrac{8.0\ \text{N}}{5.00\ \text{kg}}$

$= 1.6\ \text{m/s}^2$, in the direction of the 10.0 N force

10. This is the force of gravitational attraction.

11. This force depends on the two masses involved and the distance between their centres.

12. a. Yes, because they have masses.

    b. The attracting force will be greater in Diagram B because the masses are greater.

    c. The force of gravitational attraction varies directly with the size of the two masses involved.

13. a. The attracting force will be greater in Diagram A because the masses are closer together.

    b. The force of gravitational attraction varies inversely with the distance between their centres.

14. The force of gravitational attraction between any two masses varies directly with the product of the two masses and inversely with the square of the distance between their centres.

15. $F_g = \dfrac{Gm_1m_2}{r^2}$

16. a. $\vec{F}_g$ represents the magnitude and direction of the force of gravitational attraction.

    b. G represents Newton's gravitational constant $\left(6.67 \times 10^{-11}\ \text{N} \bullet \text{m}^2/\text{kg}^2\right)$.

    c. m_1 represents mass of first object.

    d. m_2 represents mass of second object.

    e. r represents the distance between the centres of the two masses.

    f. F_g represents the magnitude of the force of gravitational attraction.

17. $F_g = \dfrac{Gm_1m_2}{r^2}$

$= \dfrac{6.67 \times 10^{-11}\ \text{N} \bullet \text{m}^2/\text{kg}^2 \times 0.100\ \text{kg} \times 5.97 \times 10^{24}\ \text{kg}}{\left(6.40 \times 10^6\ \text{m}\right)^2}$

$= 0.972\ \text{N}$ (3 significant digits)

18. Yes, because an unbalanced force is applied.

19. $a = \dfrac{F}{m}$

$= \dfrac{0.972\ \text{N}}{0.100\ \text{kg}}$

$= 9.72\ \text{m/s}^2$ (3 significant digits)

20. This is the acceleration due to gravity or the acceleration of free fall.

21. The symbol for the acceleration of falling objects is g.

22. Equation 1: $F_g = m_1 \times g$

Equation 2: $F_g = \dfrac{Gm_1m_E}{r^2}$

Since $F_g = F_g$, you can write $m_1 \times g = \dfrac{Gm_1m_E}{r^2}$. Cancel m_1 on each side to get $g = \dfrac{Gm_E}{r^2}$.

23. $g = \dfrac{Gm_E}{r^2}$

$= \dfrac{6.67 \times 10^{-11}\ \text{N} \bullet \text{m}^2/\text{kg}^2 \times 5.97 \times 10^{24}\ \text{kg}}{(6.40 \times 10^6\ \text{m})^2}$

$= 9.72\ \text{m/s}^2$ (3 significant digits)

24. The value of g depends on the mass producing the field and the distance from its centre.

25. a. The force of gravitational attraction is also called the weight of an object.

b. Another symbol for F_g is W.

c. Weight would be different on each other planet because weight is dependent on gravitational attraction, which in turn depends on the mass of the planet.

26. a. $F = m \times a$

$\downarrow \quad \downarrow$

$W = m \times g$

b. $W = m \times g$

$= 50.0\ \text{kg} \times 10.0\ \text{m/s}^2$

$= 500\ \text{N}$

27. a. The two masses are inertial mass and gravitational mass.

b. Inertial mass is the mass of an object that wants to maintain a state of uniform motion.

c. $m = \frac{F}{a}$

d. Gravitational mass is the mass that is attracted by the force due to gravity.

e. $m = \frac{F_g}{g}$

f. Yes, these masses are really the same.

28. a. $m = \frac{\vec{F}}{\vec{a}}$

$= \frac{10.0\ \text{N}}{10.0\ \text{m/s}^2}$

$= 1.00\ \text{kg}$

b. $m = \frac{\vec{F}_g}{\vec{g}}$

$= \frac{9.81\ \text{N}}{9.81\ \text{m/s}^2}$

$= 1.00\ \text{kg}$

29.

Question	Mass	Weight
a.	the amount of inertia in an object	the force of gravitational attraction on an object
b.	m	W
c.	kilograms (kg)	newtons (N)
d.	1.0 kg	10 N
e.	Yes, mass is constant.	No, g on the moon is different than g on Earth.

30. The triple beam balance would measure the mass of an object.

31. The spring scale would measure the weight of an object.

32. Triple beam balance should be measured in kilograms, and the spring scale should be measured in newtons.

33. a. They are measuring gravitational mass.

b. Use $W = m \times g$

34. Force is caused by the falling mass of 1.00 kg.

$$\therefore F = W = m \times g$$
$$= 1.00\ \text{kg} \times 9.81\ \text{m/s}^2$$
$$= 9.81\ \text{N}$$

The entire system has to be accelerated; thus, the total mass is 3.00 kg.

$$\therefore a = \frac{F}{m}$$
$$= \frac{9.81\ \text{N}}{3.00\ \text{kg}}$$
$$= 3.27\ \text{m/s}^2 \ (3 \text{ significant digits})$$

35. The unbalanced mass is 2.00 kg, and this will cause the unbalanced force.

$$F = W = m \times g$$
$$= 2.00\ \text{kg} \times 9.81\ \text{m/s}^2$$
$$= 19.62\ \text{N}$$

To calculate the acceleration, you need the mass of the entire system.

$$\therefore a = \frac{F}{m}$$
$$= \frac{19.62\ \text{N}}{4.00\ \text{kg}}$$
$$= 4.91\ \text{m/s}^2 \ (3 \text{ significant digits})$$

36. a. $W = m \times g$
$= 50.0\ \text{kg} \times 9.81\ \text{m/s}^2$
$= 491\ \text{N}$ (3 significant digits)

b. The scale would read zero since the scale and you are falling at the same rate of acceleration.

37. This is called weightlessness or free fall.

38. Yes, it will because your body is accelerating at $9.81\ \text{m/s}^2 (g)$.

39. Yes, you will reach a maximum speed.

40. This maximum speed is called terminal velocity.

41. Air friction causes a terminal velocity.

Section 3: Activity 4

1. You are accelerating upward from the surface of the Earth.

2. You will move opposite to your force, or away from the boards.

3. You will move downwards into the water.

4. Yes, you might call the force on your hands a pressure.

5. This force is called the action force.

6. This force is called the reaction force.

7. Yes, they are equal in magnitude. You know because the wall does not fall over and you do not fall backward.

8. These forces are called an action-reaction pair.

9. They are opposite in direction and they act on different objects.

10. For every action there is an equal but opposite reaction.

11.

Diagram	Action Force	Reaction Force
A	elevator floor pushing on man's feet	man's feet pushing on floor
B	tires pushing on earth	earth pushing on tires
C	racket pushing on ball feet pushing on ground tires pushing on ground	ball pushing on racket ground pushing on feet ground pushing on tires

12. The action force is the horse pulling on the cart and the reaction force is the cart pulling on the horse.

13. The forces act on different objects. The acceleration of the cart is determined by the force acting on the cart, not by the force of the cart acting on the horse. Since there is only one force on the cart, then the cart should move and accelerate.

14. a. $\vec{a} = \dfrac{\vec{F}}{m}$

$= \dfrac{10.0\ \text{N}}{3.00\ \text{kg}}$

$= \dfrac{10.0\ \cancel{\text{kg}} \bullet \text{m/s}^2}{3.00\ \cancel{\text{kg}}}$

$= 3.33\ \text{m/s}^2$, in the direction of the force (3 significant digits)

b. $\vec{F} = m \times \vec{a}$

$= 1.00\ \text{kg} \times 3.33\ \text{m/s}^2$

$= 3.33\ \text{N}$, in the given direction (3 significant digits)

c. $\vec{F} = m \times \vec{a}$

$= 2.00 \text{ kg} \times 3.33 \text{ m/s}^2$

$= 6.66 \text{ N}$, in the given direction (3 significant digits)

d. $\vec{F}_{\text{total}} = 3.33 \text{ N} + 6.66 \text{ N}$

$= 10.0 \text{ N}$, in the given direction (This is the action force.)

e. The reaction force is 3.33 N by Block A in the opposite direction to the applied force.

f. The reaction force is 6.66 N by Block B in the opposite direction to the applied force.

g. $\vec{F}_{\text{total}} = 3.33 \text{ N} + 6.66 \text{ N}$

$= 10.0 \text{ N}$, in the opposite direction to the applied force (This is the reaction force).

h. They accelerate because there is only one force acting on the blocks and this is an unbalanced force causing acceleration.

i. The person would, but the force of friction between his feet and the Earth is greater than 10.0 N.

Section 3: Follow-up Activities

Extra Help

1. The velocity of an object remains constant unless a force acts on the object.
2. The three situations are as follows:
   - The force of tires on the pavement stop a car.
   - A rocket will not move unless the force of the engines exert upon it.
   - A comet will move through space forever unless otherwise impeded.
3. Force equals mass times acceleration ($F = ma$).
4. The apparatus is called an air track.
5. This apparatus is used because it reduces the effect of friction.
6. The distances between the positions of the carts are increasing.
7. The velocity of the cart must be increasing as it moves down the track.
8. Another name for increasing velocity is acceleration.
9. The acceleration of the cart doubled when the force was doubled and tripled when the force was tripled.
10. The acceleration is halved when the mass of the cart is doubled, and reduced to one-third when the mass of the cart is tripled.

11. The results in Activity 2 did not necessarily show doubling or tripling or a reduction to one-half or one-third. However, the results were consistent in that increasing the pulling force increased the acceleration of the cart and increasing the cart mass decreased the acceleration of the cart.

12. The results were not the same due to a greater amount of friction with the cart and pulley apparatus in the experiment.

13. The cart exerts an opposite force on the weight. This was shown when the weight fell faster when it did not have the cart to pull.

14. a. Newton's Third Law of Motion
    b. Newton's First Law of Motion
    c. Newton's Second Law of Motion
    d. Newton's Third Law of Motion

15. $F_g = \frac{Gm_1m_2}{r^2}$ and $F_g = m \times g$ or $W = m \times g$

16. $g = \frac{Gm}{r^2}$ and $g = \frac{F_g}{m}$ or $g = \frac{W}{m}$

17. Mass is constant while weight varies with g.

18. G is the gravitational constant $\left(6.67 \times 10^{-11} \text{N} \bullet \text{m}^2 / \text{kg}^2\right)$. g is the acceleration due to gravity $\left(9.81 \text{ m} / \text{s}^2\right)$.

19. Although the sample sentences will vary, the definitions should be consistent.

Term	Definition	The Term in a Complete Sentence
friction	the force that opposes the motion between two surfaces	By lubricating two surfaces with oil, you can reduce the friction between them.
inertia	the tendency of an object to remain at rest once at rest or to remain in motion once in motion	The inertia of the oil tanker is so tremendous that tugboats are used to maneuver it.
mass	a measure of the quantity of matter an object contains	The mass of some black holes may be larger than thousands of stars.
weight	the force of gravity on an object	The sumo wrestler has a weight of over 600 lbs.
force	a push or a pull on something Force is measured in newtons (N).	The forces exerted on your head as you fall off a bicycle are so large that permanent damage can result. This is why you should always wear a helmet.

20. a. $\vec{a} = \dfrac{\vec{F}}{m}$

$= \dfrac{50.0\ \text{N}}{10.0\ \text{kg}}$

$= \dfrac{50.0\ \cancel{\text{kg}} \bullet \text{m/s}^2}{10.0\ \cancel{\text{kg}}}$

$= 5.00\ \text{m/s}^2$, in the direction of the force

b. unbalanced force $\vec{F} = 50.0\ \text{N} - 10.0\ \text{N}$

$= 40.0\ \text{N}$, horizontally in the direction of the larger force

$\therefore \vec{a} = \dfrac{\vec{F}}{m}$

$= \dfrac{40.0\ \text{N}}{10.0\ \text{kg}}$

$= \dfrac{40.0\ \cancel{\text{kg}} \bullet \text{m/s}^2}{10.0\ \cancel{\text{kg}}}$

$= 4.00\ \text{m/s}^2$, in the direction of the 50.0 N force

c. It is an inertial mass.

d. The reaction force is 50.0 N by the ball on the object producing the 50.0 N force.

Enrichment

1. **Textbook question 5:** Air bags distribute the decelerating forces acting on the occupant of a vehicle over a longer period of time and also over a larger area. The result is that the force on any one part of the occupant's body may not be enough to cause serious injury.

   Textbook question 8: The answers will vary but the students' reasons should be similar to the following:

   - Calgary is at a high altitude relative to most other Canadian cities. At high altitudes the pressure is low making it difficult for takeoff.
   - Warm temperatures create lower air pressure as well, thus making it difficult for takeoff.

2. **Textbook question 2:** Answers will vary. The balance may be something as simple as a board on a wedge-shaped block with various-sized objects for weights. Coins would work well for weights since you could have various masses and have as many of the same size masses as you need.

   You could calibrate the scale by finding the masses of various sizes of coins with a standard balance at school or by weighing several objects of known mass, finding the difference in terms of number of coins. Divide to get the mass of an individual coin.

   The instrument may not be very accurate due to a large amount of friction at the pivot point. Also, the board used may vary in density and mass on each side. The balance will only be as precise as the smallest weight that you use.

3. The wing that is shaped like Wing B has less lift. An airplane with a wing shaped like Wing B must reach a higher speed for takeoff, thus requiring a longer runway. However, once in the air this wing has less drag enabling the airplane to fly at higher velocities.

Formula Sheet

The following is a list of formulas that you will need for this module.

- $\vec{F} = m\vec{a}$
- $\Delta\vec{d} = \vec{v}t$
- $\vec{v}_{ave} = \dfrac{\Delta\vec{d}}{\Delta t}$
- $\vec{a} = \dfrac{\vec{v}_f - \vec{v}_i}{\Delta t}$
- $\vec{F}_g = m\vec{g}$
- $F_g = \dfrac{Gm_1m_2}{r^2}$

Centimetre Ruler

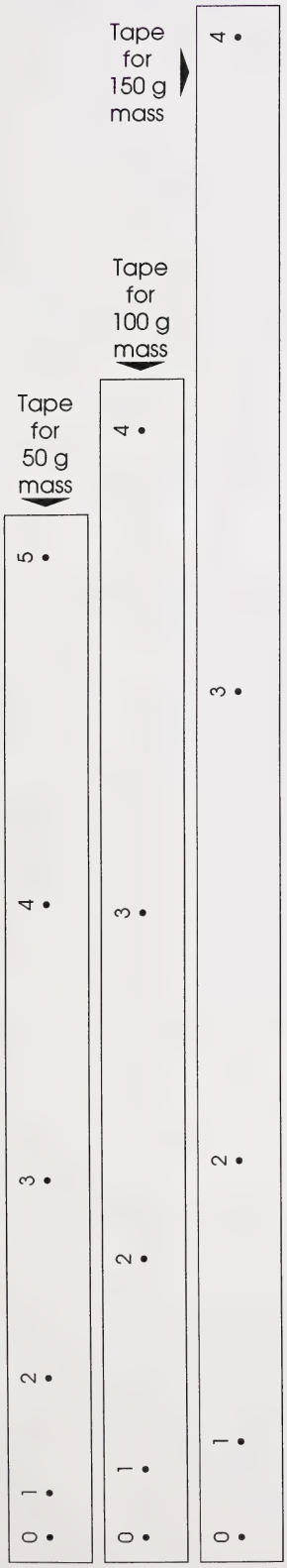


Ticker Tape for Section 2: Activity 4, Investigation: The Acceleration of Free Fall

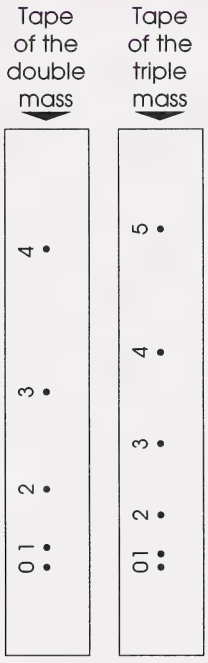


cker Tapes for Section 3: Activity 2, Investigation: Factors Affecting Acceleration of an Object

Part A Ticker Tapes



Part B Ticker Tapes



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Science 20

Student Module Booklet

Module 7

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